Vermont Water Resources and Lake Studies Center
Annual Technical Report
FY 2014

Introduction

The Vermont Water Center works with faculty at Vermont colleges and universities to support water resources related research. Research priorities are identified each year, determined by the Water Center Advisory Board, as well as through collaboration with the State of Vermont Department of Environmental Conservation, Lake Champlain Sea Grant, Lake Champlain Basin Program, and other programs in the state. The Director works with state, regional, and national stakeholders to identify opportunities to link science knowledge with decision making in water resource management and policy development. The Director of the Water Center is also the Director of Lake Champlain Sea Grant (LCSG) and both programs share the same advisory board, which leverages the strengths of each program. The LCSG currently has limited funds available for research, but is dedicated to research extension through outreach and education. By working closely with LCSG, research extension of the VWRLSC is enhanced. The VWRLSC and LCSG are not the only programs to have this partnership and the national offices for the USGS and NOAA have held preliminary discussions on how best to capitalize on the mutual and different strengths of these organizations. The Director of the Water Center is also a member of the Steering Committee of Lake Champlain Basin Program (LCBP) and regularly brings information from Center-funded projects to the attention of LCBP committees. His activity on these committees also helps to inform the directions of the Water Center and has led to a number of productive partnerships.

Research Program Introduction

During the 2014-2015 project year, the Vermont Water Resources and Lake Studies Center funded two projects; proposals were reviewed by external peers and the advisory board. Water resources management research, including physical, biological, chemical, social science, and engineering were solicited in the RFP. These topics are of interest to stakeholders of the VWRLSC, including the Vermont Department of Environmental Conservation, the Lake Champlain Basin Program, the Lake Champlain Research Consortium, and Lake Champlain Sea Grant.

The research projects supported by the 104b funds in the 2014-15 project year were:

1. Organic phosphorus forms and transformations in Lake Champlain stream corridor soils, Year 2. Donald S. Ross (Department of Plant and Soil Sciences, University of Vermont) and Beverley C. Wemple (Department of Geography, University of Vermont).

2. An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish. J. Ellen Marsden (Rubenstein School of Environment and Natural Resources, University of Vermont) and Jason D. Stockwell (Rubenstein School of Environment and Natural Resources, University of Vermont).

In addition, one project was completed in 2015 from the 2013-14 funding cycle:

3. Evalutation effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff. Beverley C. Wemple (Department of Geography, University of Vermont) and Donald S. Ross (Department of Plant and Soil Sciences, University of Vermont).

While graduate students are often supported on the projects funded by the VWRLSC, students have not previously been able to directly apply for funds. During the 2014-15 RFP graduate students were explicitly invited to submit proposals for up to $10,000 with their advisor's support for matching funds and as named PI. One proposal was submitted and funded through external gift funds the VWRLSC was able to secure from the Lintilhac Foundation. Future RFPs will continue to encourage graduate students to submit proposals.

Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff

Basic Information

Title:	Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff
Project Number:	2012VT65B
Start Date:	3/1/2013
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	Vermont-at-Large
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Water Quality, None
Descriptors:	roads, best management practices, BMPs, water quality, sediment, phosphorus
Principal Investigators:	Beverley Wemple, Donald Ross

Publications

There are no publications.

1. **Title: Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff**

2. Project type: Research

3. Focus category: nutrients, non-point source pollution, water quality

4. Research category: water quality

5. Keywords: roads, best management practices, BMPs, water quality, sediment, phosphorus

6. Start date: March 1, 2013

7. End date: February 28, 2014 (no cost extension to December 31, 2014)

8. Principal investigators:

Beverley C. Wemple, Associate Professor, University of Vermont, bwemple@uvm.edu, 802-656-2074
Donald S. Ross, Research Associate Professor, University of Vermont, dross@uvm.edu, 802-656-0138

9. Congressional District: Vermont-at-large

10. Abstract:

Gravel roads in rural settings can adversely affect water quality through the contribution of excess runoff, sediment and sediment-bound nutrients to receiving waters. These contributions can occur through chronic wash off from the road surface and through catastrophic gullying and road bed failure during extreme storms. To mitigate the adverse effects of roads on water quality, a number of Best Management Practices (BMPs) have been developed and tested in diverse settings. Although these practices appear to reduce erosion and mass wasting from roads, evidence of the benefit of any single BMP on pollutant reduction is limited, and studies quantifying these reductions in rural Vermont do not exist. We partnered with the Vermont Agency of Transportation's Better Backroads Program and the Vermont Agency of Natural Resources Ecosystem Restoration Program (within the Department of Environmental Conservation) to evaluate the effectiveness of BMPs on rural roads in addressing water quality protection. The project addresses key needs of the Vermont Agency of Natural Resources in their charge to address water quality concerns within the Lake Champlain basin and throughout the state.

11. Budget Breakdown:

	PIs: Wemple, Ross Evaluating Effectiveness of BMP implementation		
Cost category	**Federal**	**Non-Federal**	**Total**
Salaries and wages			
- Principal Investigator - Wemple	$ -	$ 14,347	$ 14,347
- Co-Investigator - Ross	$ -	$ 4,537	$ 4,537
- Graduate students	$ -	$ -	$ -
- Undergraduate Students	$ 2,880	$	$ 2,880
- Others: Technician	$ 10,080	$ -	$ 10,080
- Wages	$ -	$ -	$ -
- Total Salaries and Wages	$ 12,960	$ 18,884	$ 31,844
Fringe Benefits	$ 1,128	$ 7,988	$ 9,116
Supplies	$ 4,800	$	$ 4,800
Equipment	$ -	$ -	$ -
Services or Consultants	$ -	$ -	$ -
Travel	$ 3,680	$	$ 3,680
Other Direct Costs (lab fees)	$ 4,608	$ -	$ 4,608
Total Direct Costs	$ 27,176	$ 26,872	$ 54,048
Indirect costs on federal share	$ 14,267	n/a	$ 14,267
Indirect costs on non-federal share	n/a	$ 14,108	$ 14,108
Total Estimated Costs	$ 41,443	$ 40,980	$ 82,423
Total costs at Center campus	$ 41,443	$ 40,980	$ 82,423
Total costs at other University	$ -	$ -	$ -

12. Budget Justification:

Year 1 field activity began in July 2012, and supported a field technician through June 2013. Funds for Year 2 provided continued support for a field technician and supported a graduate student and undergraduate student engaged in the project. Wemple and Ross contributed their time to the project through a cost-share of their salaries.

Funds for supplies covered materials for silt fences. Funds for laboratory processing of samples were used to generate sediment and phosphorus mass data. Travel funds were used for regular field visits and for meetings with participating town officials and staff and project cooperators in the state agencies.

13. Title: **Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff**

14. Statement of regional or State water problem

Low-volume gravel roads in rural and upland settings are recognized as contributors to water quality impairment through contributions of overland flow, sediment, and nutrients to receiving water ways. These contributions can occur through chronic inputs of water and pollutants washed from the road surface during storm events or through episodic and often catastrophic road failure by mass wasting during extreme storms. Research studies in forested areas of the eastern U.S. (Swift 1984; Egan, Jenkins et al. 1996) and elsewhere (Ziegler and Giambelluca 1997; Wemple, Swanson et al. 2001; Borga, Tonelli et al. 2005; Lane, Hairsine et al. 2006) have documented rates of erosion and mass wasting from roads and impacts on water quality. A recent study on roads in an agricultural watershed in central New York documented a high level of road-stream connectivity and identified roads as an important vector for pollutant delivery to waterways (Buchanan, Falbo et al. 2012).

Within Vermont, inventories are emerging to document the extent and form of road-drainage impairments to water quality (VBB 2008; Bartlett, Bowden et al. 2009). Watershed planning efforts in the state call for attention to this issue (VCCAP 2009; VTANR 2010), however little guidance exists to assist managers with targeting management or restoration activities that would provide maximum benefit in reducing water quality impairments from roads. Recommendations for the mitigation of road impacts on water quality are available in the scientific literature (see for example Colbert 2003), however previous assessments on forest roads in the region show very low levels of implementation and compliance with best management practices (BMPs) (Brynn and Claussen 1991; Schuler and Briggs 2000).

This project aimed to evaluate effectiveness of best management practices for reducing water quality impacts of rural, unpaved roads in upland settings of Vermont and provide information to support decision-making on road maintenance and water quality improvement at the town and state level.

15. Statement of results or benefits

This research resulted in measurements that quantify pollutant production from gravel roads typical of those in rural settings throughout Vermont and other upland rural settings of the northeastern US. Data collected through the study also allowed the quantification of pollutant reduction associated with recommended BMPs for gravel roads. We evaluated past Vermont Better Backroads (VBB) projects to determine long-term viability of BMP installations and evaluate factors that contribute to BMP success or failure. Finally, we interviewed a set of town officials and staff to understand current expenditures on rural road maintenance and evaluate cost trade offs with BMP implementation. Findings from the study should be directly applicable to the mandate under Vermont Act 110[1], passed by the Vermont legislature in 2010, to develop standards and best

[1] Town Road and Bridge Standards (January 4, 2011; Vermont Agency of Transportation). Section 17, paragraph 996 (a) and (b) of Vermont Act 110 directed the Vermont Agency of Transportation (VTRANS) to work with municipal representatives and the Agency of Natural Resources (ANR) to develop standards and best management practices for roads and bridges. These recommendations are now in the document titled Town Road and Bridge Standards (January 4, 2011) and were developed by a Task Force of staff members from VTRANS and ANR, along with town officials and staff of Better Backroads, a program of Northern Vermont Resource Conservation and Development Council.

management practices to minimize water quality degradation from roads. The results of the proposed study will allow managers to target candidate road segments for future treatments and quantify pollution reduction associated with the implementation of BMPs.

16. Nature, scope and objectives of the project

This project aimed to quantify the rate, magnitude and temporal dynamics of pollutant (sediment and phosphorus) production from gravel roads typical of rural upland settings in Vermont and to identify pollutant reductions associated with the application of select BMPs on roads. Specific objectives of the project were to (1) quantify the reduction in sediment and phosphorus runoff from gravel roads associated with the implementation of selected BMPs, and (2) develop information to support decision making that can be used to identify and optimize allocation of financial and technical resources to minimize erosion and pollutant production on Vermont's gravel roads. Our approach involved three key elements, including an ***experimental component*** to evaluate BMP effectiveness at reducing pollutant runoff from roads, a ***retrospective assessment*** of past Better Backroads projects to evaluate longevity and factors associated with BMP success or failure, and a ***cost analysis*** of road maintenance and BMP implementation practices in a select set of Vermont towns.

17. Methods, procedures and facilities

Our work included field, laboratory, interviewing, and analysis procedures addressing our overarching objectives. Field work was conducted between 2012 and 2014 from April to November of the first two years and concluding in August of 2014. We worked alongside partners in the Vermont Agency of Transportation's Better Backroads program, and in consultation with town select boards and road crews in towns participating in the study. Our approach and methods are described below.

Experimental methods

Methodology for the experimental BMP installations involved bulk sample collection below road drainage outlets (cross-drain culverts) using a before-after treatment/control design. We worked in towns of the Mad River Valley, Vermont, in collaboration with town staff (town administrator, road foreman) and in consultation with town select boards. BMP treatments (Table 1) were selected in consultation with the lead technician of the Vermont Better Backroads Program. We selected and monitored 9 study sites, each of which included a road segment held as an untreated control, along with a matched road segment that was treated with a selected BMP. Each of the treated sites was identified by town road crews as in need of drainage improvement. Three additional sites were selected in summer 2012, but were subsequently abandoned by the town of Warren, Vermont due to excessive storm damage incurred during summer 2013. Each road site selected for study (both treatment and control site) were demarcated by cross-drain culverts, yielded a monitored road length of between 25 – 100 m. Detailed site plans for the treated segment were prepared and filed as part of an application to the Vermont Better Backroads program.

Bulk sediment samples at each monitored road segment were collected at culvert outfalls in a silt fence, fabricated from plastic to retain coarse sediment and water, and landscaping fabric to allow drainage of effluent and reduce risk of failure (Figure 1). Silt fences were serviced between storm events. At each servicing interval, retained sediment was removed from the silt fence and measured as a bulk wet volume. A subsample of up to 19 L (5 gallons) of the collected material was retained and returned to the lab where it was dried and weighed in order to determine dry mass. This dry mass fraction was then applied to the total volume collected to determine a dry bulk mass collected at each site for each servicing interval. A subsample of the dried sediment was analyzed for total phosphorus by microwave assisted digestion with concentrated nitric acid and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) using standard methods in the Agricultural and Environmental Testing Laboratory at the University of Vermont.

Figure 1: Plastic and filter fabric silt fence, installed out culvert outfall, with bulk sample collected after storm event in summer 2012

Table 1: Description of BMP treatments installed on selected road sites

BMP treatment	Description
1. Rock-line ditch	Install up to 1 mile of rock in ditches lined with geotextile fabric
2. Stone check dams and turnouts	Install stone check dams and turnouts at spacing in compliance with BMP recommendations from Better Backroads staff to slow erosive ditch flow
3. Compost socks	Install compost socks in ditches to trap sediment and slow flow
4. Grass seeding[1]	Apply hydroseeding mix to ditch and adjacent roadside to initiate revegetation of ditches

[1] This treatment was intended for study but abandoned due to excessive storm damage at study sites in summer 2013 and inability of road crews to implement treatments. Pre-treatment data were collected for sites selected for study.

Retrospective assessment

To understand how Better Backroads erosion control projects have performed since their installation, we conducted a retrospective assessment of 45 historic Vermont Better Backroads (VBB) projects, or 12% of the total number of completed VBB projects. Sites were chosen based on two criteria: first, the availability of paper project files that outlined precise project locations and the work completed during the construction phase and second, geographic proximity to other project sites and within north central Vermont, in order to minimize travel time and expense. Project sites were selected regardless of BMP type or age. The geographic and age distribution of assessed sites is shown in comparison to all Better Backroads project sites in Figure 2 and Figure 3.

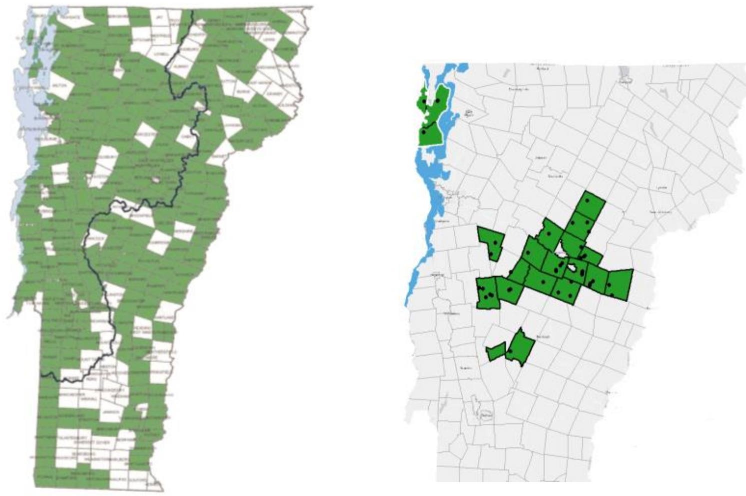


Figure 2: Left panel: map of Vermont towns (in green) participating in the Vermont Better Backroads program. Right panel: North-central Vermont towns (in green) with project sites assessed for this study and locations of those sites (black dots).

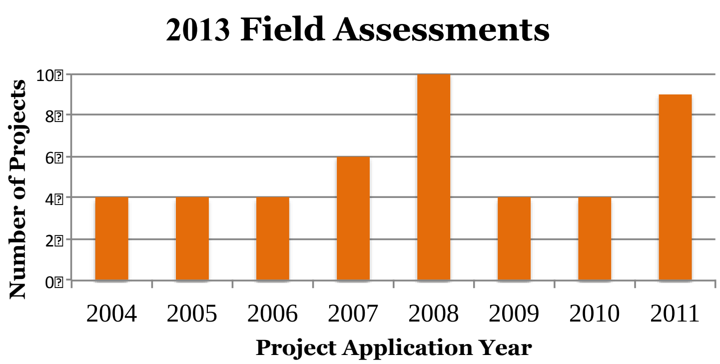


Figure 3: Distribution years of assessed projects.

For this study, Best Management Practices were grouped into four categories based on construction techniques, materials, purpose and behavior over time (RC&D, 2009).

- **Stonework** includes the following BMPs: stone lined ditches, check dams, turnouts, settling pools, plunge pools, rock aprons, stone dikes and stone water bars.
- **Culvert** work included the installation or replacement of stream and ditch culverts, and any associated headwalls, whether log, stone or concrete.
- **Revetments**, although constructed with stone, were grouped separately from Stonework due to their placement on the landscape with respect to water flow and their behavior over time. Revetments observed in this study were entirely riprap systems placed on the banks of streams or lakes, or above or below roads cutting across steep slopes. Also included in this category, but not observed in the field, were gabion walls, log or timber cribs, and rock walls.

- **Vegetated Soil Stabilization** comprised primarily of grass lined ditching, seeding and mulching, and one log water bar. Included in the category, but not observed in the field, were live wattle/stake placement, sprig or plug planting, and terracing.

We reviewed historical Better Backroads project files to guide our selection of project sites and BMPs to assess. A tally of the BMPs described in Better Backroads project folders was collected from the paper files of the 2007, 2009 and 2011 application years. The distribution of the BMPs, grouped by BMP types described above, is displayed in Figure 4. This review showed that the program typically funds over half its applications for stonework projects, roughly one quarter of the applications for culvert work, and almost equal proportions of the remaining quarter of projects for revetment construction and vegetated soil stabilization. During the field season of 2013, 106 BMPs were assessed in 45 project locations (any VBB "project" could have one or more BMPs installed). The BMP types assessed during the 2013 field season was approximately representative of the total BMP distribution funded by Better Backroads since 2004 (Figure 5).

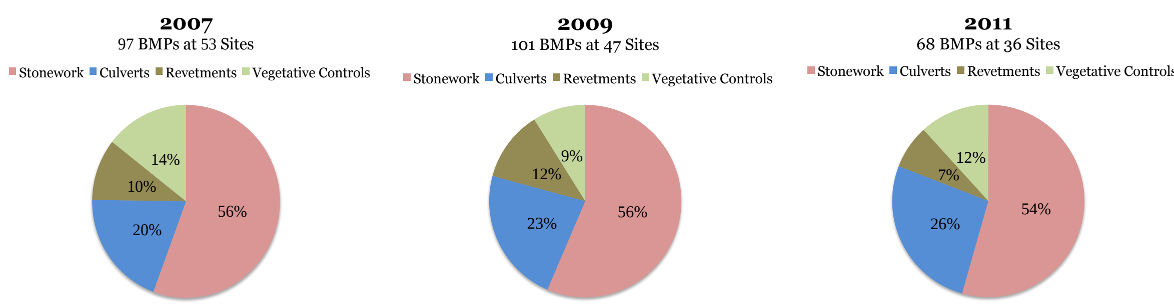


Figure 4: Distribution of BMP types funded over three application years.

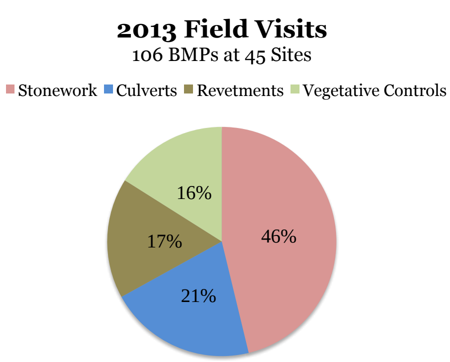


Figure 5: Distribution of BMP types assessed for this study.

At each project site selected for our assessment, each BMP constructed as part of a Better Backroads project was assigned a condition of ***intact*** if the BMP appeared to be functioning to improve drainage and reduce on site erosion, ***compromised*** if some evidence of reduced performance to drain water and reduce erosion was evident, and ***failed*** if the BMP as recorded on the project file archive has been undermined or destroyed Figure 6. The evaluation criteria were established by comparing the BMPs to other BMPs informally assessed earlier in the field season, by comparing the BMP to date with photos taken immediately after implementation, and through visual evidence of BMPs reducing the volume of sediment traveling to receiving waterways. We note that although each BMP was assessed individually using the coding described above, for the purposes of site-level statistical analysis, each BMP project *site* was later recoded as described below.

Figure 6: Examples of assessed Better Backroads sites and condition of BMPs -- left: *intact* stone lined ditch; middle: culvert *compromised* by debris partly plugging inlet; right: *failed* BMP installation showing evidence that stone and stabilization fabric have been undermined.

At each assessed project site, additional observations were made to evaluate site conditions leading to success or failure of installed BMPs. These observations included (1) road grade, (2) placement of road as cross-slope or slope-parallel, (3) road profile (crowned, insloped, outsloped), (4) presence or absence of vegetation between the BMP and the road, and (5) age of the BMP (i.e. years since BMP installation). In addition, we used mapped extents of flood impact zones published in the report by Castle et al., 2013[2] to code each assessed site with a binary variable for exposure to an extreme flood since BMP installation.

For the purposes of statistical analysis, overall project (site) condition was coded as either ***all intact*** if all BMPs assessed at the site were rated as intact or ***some BMPs compromised or failed*** when a compromised or failed rating was assigned to one or more BMPs at the site. Reclassifying project condition as a binary variable enabled use of a logistic regression of the field data to examine the likelihood that measured variables could explain project condition. For selected BMPs (stone lined ditches, n=25) and culverts (n=18) where number of observations exceeded 15, we conducted logistic regression analysis on these individual practices. Logistic regressions were performed using the SPSS statistical software package.

Cost analysis

During the summer of 2014, road foremen and town administrators in the towns of Corinth, Huntington, Hyde Park, Waitsfield and West Windsor agreed to participate in interviews designed to assess town expenditures on their roads. All towns had previously received Better Backroads grants and had implemented BMPs according to Better Backroads recommendations.

[2] Castle, Stephanie S., Eric A. Howe, Emily L. Bird and William G. Howland (2013). Flood Resilience in the Lake Champlain Basin and Upper Richelieu River. Lake Champlain Basin Program. Retrieved March 27, 2014, from http://www.lcbp.org/wp-content/uploads/2013/04/FloodReport2013_en.pdf

Before participating in the interviews, each town provided a line item list of road budgets and expenditures for the most recent calendar or fiscal year. Interviews captured town-specific information that enabled calculation of the proportion of expenditures dedicated to five unpaved road maintenance tasks occurring outside of the winter months:

1. Routine Maintenance, defined as tasks required for basic care of well-maintained unpaved roads, e.g. routine grading, chloride application, mowing
2. Mud Season Repairs, defined as seasonal fixes to address road erosion and sediment deposition during spring melts and temporary winter thaws, e.g. filling potholes and ruts, smoothing washboards
3. Fixing “Problem Roads,” defined as repeated maintenance of road damage caused by erosion from the road or deposition in ditches, including gravel application, ditch reshaping and excavation, clearing of obstructed culverts
4. Constructing BMPs, defined as capital improvements to roads, roadside ditches or slopes
5. Maintaining BMPs, defined as repairs to, or excavation of sediment from, operating BMPs

To divide road crew salaries into expenditures by task, we collected monthly information on the number of hours worked per week, the number of employees, and the percentage of crew time spent working on unpaved roads. Additionally, we calculated the distribution of vacation hours, winter maintenance hours, and hours spent on the five tasks listed above during the non-winter season.

To estimate road materials costs, we selected budget line items that pertained to non-winter unpaved road maintenance and asked the road foreman to estimate the division of materials used over the same five maintenance tasks. Material line items included, but were not limited to, fuel, culverts, chloride, gravel or aggregate, stone, hay, seed, mowing, and equipment rental. Because the intent of this portion of the study was to itemize funds spent on unpaved road maintenance during the non-winter months, line items associated with equipment maintenance or repairs, town garage expenses, signage, paving or tar patching, and materials used for winter maintenance, such as sand and salt, were excluded from our analysis.

18. Findings

Experimental manipulations

Results of the experimental portion of our study show that unpaved roads are sites of extensive sediment and phosphorus production in upland settings of Vermont and that BMPs, when properly installed, can markedly reduce pollutant production from unpaved roads. Among events monitored over the study period, sediment trapped in silt fences at study sites ranged from less than 1 kg to more than 800 kg (Figure 7). For individual storm events, collects of over 100 kg of sediment per site were common at many of the road sites. Laboratory samples showed that bulk sediment collected at the silt fences ranged from 70 to nearly 100% fines with total phosphorus concentrations that ranged from 350 to 600 mg P per kg soil (Figure 8).

Successive monitoring at paired control and treatment sites over the pre-treatment period allowed for the establishment of a relationship between the sites against which to assess post-treatment reductions in sediment production. In most cases, treatments were highly effective in reducing sediment production at road sites, as evidenced by the downward shift in the treatment vs. control regression line in the post-treatment period (Figure 7). For example, during the pre-treatment period a storm producing 200 kg of sediment at control sites produced roughly 400 kg of sediment at the Randell Road treatment site, 60 kg of sediment at Kew Vasseur Road treatment site, and over 400 kg of sediment at the Ski Valley site (Figure 7a). Following installation of stone-lined ditches, these treatment site rates for a similar event size were reduced to <10 kg, <20 kg, and approximately 100 kg at these three sites, respectively. Installations of check dams and turnouts were similarly highly effective at Richardson and Crossett Hill Roads in Duxbury (Figure 7b). Only one of the compost sock installations, installed at the Bragg Hill Road site in Fayston, appeared to be effective at reducing sediment runoff (Figure 7c).

The pattern of highly effective BMP installations were not evident at some sites, where post-treatment storm damaged appeared to overwhelm the capacity of installed BMPs to reduce erosion and sediment delivery. This pattern was evident at the Grout Road site, a steep road where check dams and turns outs were installed in fall 2013 but largely washed out by the time post-treatment monitoring began in summer 2014 and at the Upper Prickly Mountain Road and "3-Way" site (located at the intersection of Fuller Hill, Senor and Prickly Mountain Roads) in Warren, where extensive summer storm damage in 2013 resulted in considerable erosion at these sites, overwhelming the capacity of the compost socks to trap and retain the volume of sediment produced during storm events.[3]

[3] As of this writing (May 2015), data for several of the summer 2014 monitored storms is still awaiting processing; thus graphs for the Prickly Mountain and "3-Way" sites are not yet complete.

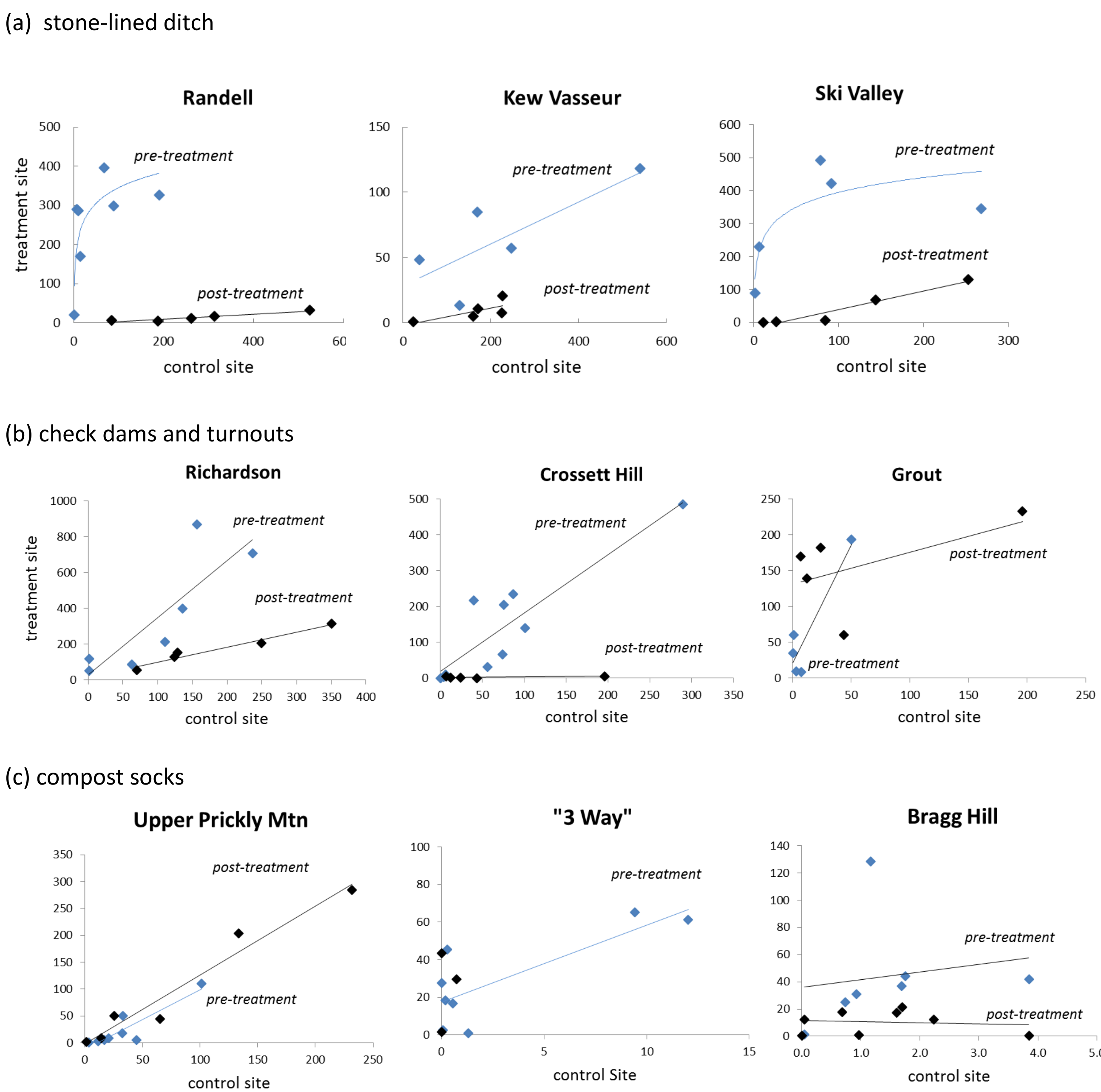


Figure 7: Plots of paired treated-control sites for three installations of stone-lined ditch in Fayston and Waitsfield (top panel), three installations of check dams and turnouts in Duxbury (middle panel), and three installations of compost socks (bottom panel) in Waitsfield Fayston. Each point represents a storm or sequence of storm events monitored between silt fence servicing intervals. Data are sediment dry mass (in kg) collected at each measurement interval. A downward shift in the relationship post-treatment is a measure of BMP effectiveness. [NOTE: all field data for 2014 season not yet available as of report publication for compost sock sites].

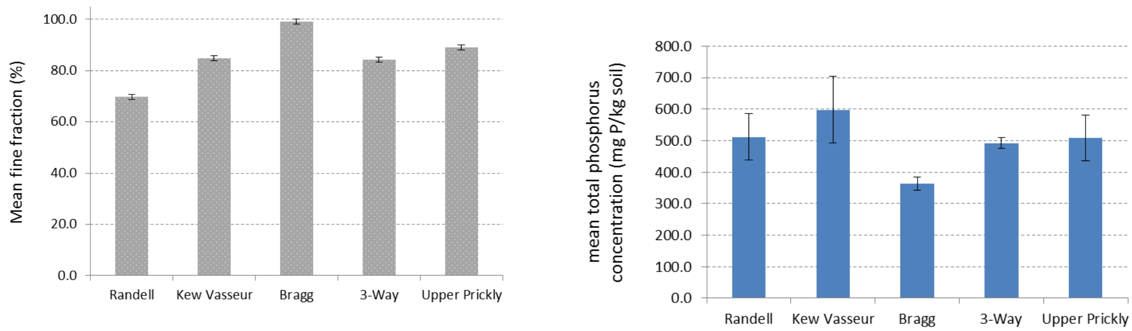


Figure 8: Mean values for samples collected of percent of bulk sample in less than 2mm size class (left panel) and total phosphorus concentration in the fine fraction (right panel). Results are presented by site for sites processed to date. Error bars are standard deviation.

Retrospective assessment

A total of 100 BMPs at 43 sites in towns of northern Vermont were assessed. Among these, 59% of assessed BMPs were intact and functioning to provide water quality protection. Thirty-one of the BMPs assessed showed some evidence of compromised performance and only 10% had failed. This performance differed slightly with road orientation, with 65% of all inspected BMPs intact on cross slope roads and only 54% intact on typically steeper, slope-parallel roads (**Error! Reference source not found.**).

Figure 9: Condition of assessed BMPs by road position.

Within the first two years of installation, virtually all inspected BMPs remained intact (**Error! Reference source not found.**). In the set of BMPs assessed 3-4 years post-treatment, stonework was the most common treatment type to show evidence of compromised performance. Stonework, like other practices, remained intact at assessed sites aged 5-8 years. In sum, nearly two-thirds of the BMPs we assessed remained intact, provided water quality protection and demonstrated viability for up to nearly a decade.

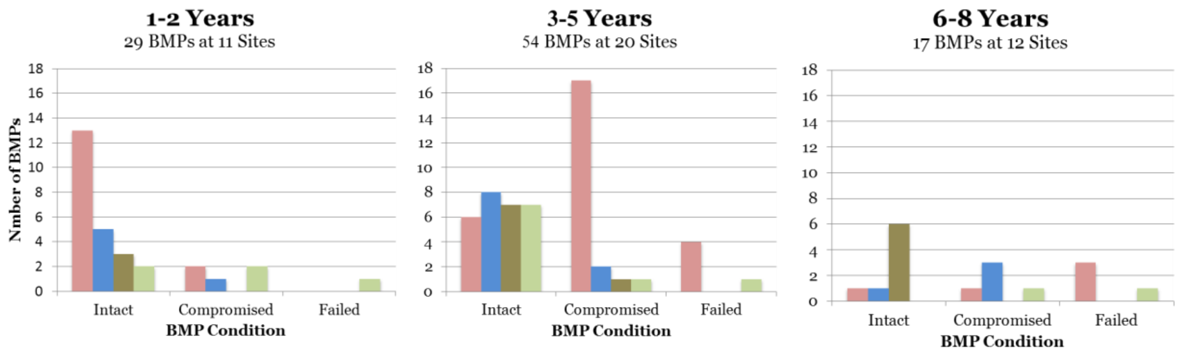


Figure 10: Condition of BMPs assessed grouped by age of project. Bar colors are as in figures 4 and 5 (pink = stonework, blue = culverts, dark green = revetments, and light green = vegetative controls).

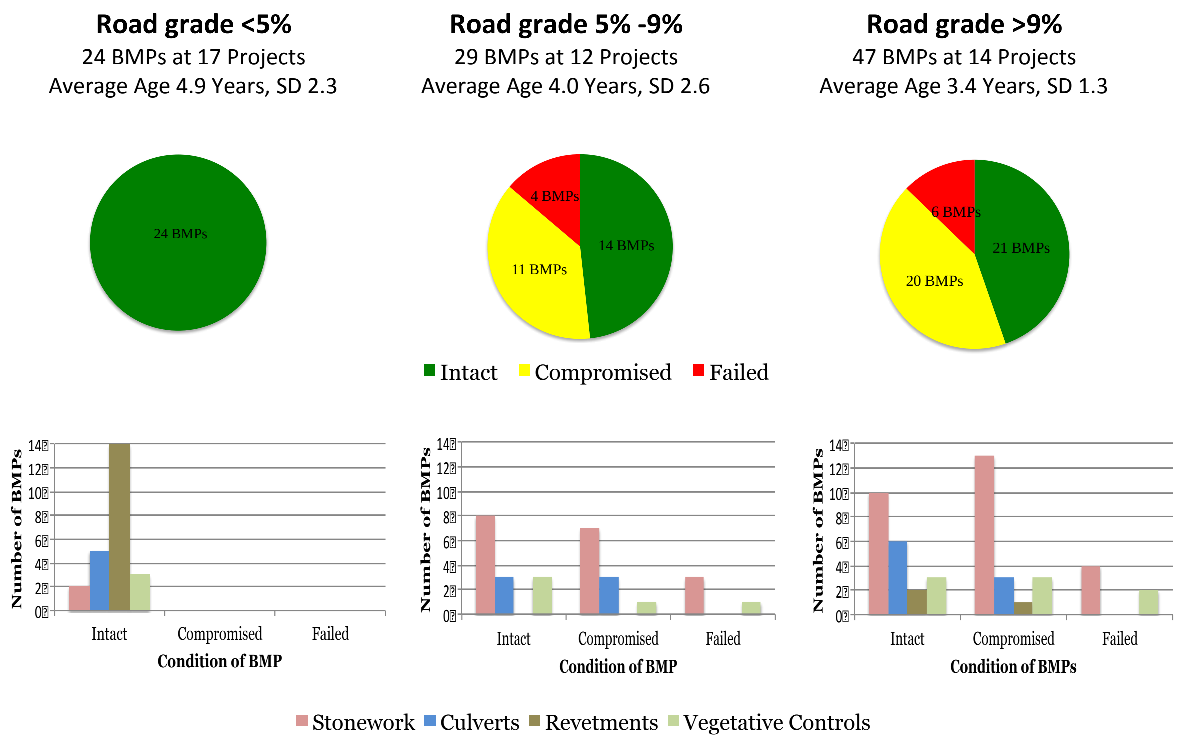


Figure 11: Condition of all assessed BMPs grouped by road grade. Upper panel shows all BMPs and percentages in each outcome category; lower panel shows BMPs color coded by type.

Statistical analysis of data by project site, using binary logistic regression, showed that grade, exposure to floods, the presence and extent of a vegetated border and the orientation of the road were factors that, individually, had a likelihood of predicting project condition (Table 2). Compromised or failed BMPs became more likely as grade increased, if the road was slope parallel instead of positioned cross slope, if no vegetated border existed between the BMP and the road, or if a site was exposed to one or more floods. Neither the age of the BMP installation or road profile could predict BMP failure. Taken together, road grade, road orientation and flood exposure were very strong predictors of BMP failure, with these three variables correctly predicting failure in 97% of the cases analyzed (Table 2).

Among individual BMP types assessed, adequate observations of stone-lined ditches (n=25) and culverts (both stream crossings and cross drains, n=18) allowed assessment of factors associated with BMP failure. Increased flood exposure and increased age were the most likely predictors of compromised or failed stone-lined ditches (Table 3). Grade, a significant predictor of BMP efficacy when grouped as a whole, was not a significant factor affecting stone-lined ditch condition when treated as an individual BMP. Degraded culvert condition, however, was correlated with increased road grade, although age remained the most significant variable (Table 4).

Table 2: Table of binary logistic regression models for prediction of the likelihood that a project will exhibit compromised or failed BMPs. Each row of the table shows results for a separate binary logistic regression model. Probability values (p) for statistically significant models are shown in bold.

Projects, **n = 43**			
Variable(s)$_i$[1]	P	-2 log likelihood	Correctly classified
Age	0.970	59.400	53.5%
Grade	**0.000**	31.498	83.7%
road profile	0.254	56.540	59.5%
road orientation	**0.015**	51.889	69.0%
vegetated border[2]	**0.001**	35.397	75.7%
flood exp[3]	**0.001**	48.283	74.4%
grade, flood exp	0.000	24.264	93.0%
grade, flood exp, veg border	0.000	12.631	90.9%
grade, flood exp, orient	0.000	21.390	**97.6%**
grade, flood exp, orient, veg border	0.000	15.283	91.9%

[1] Indicates individual or set of explanatory variables in the model

[2] Vegetated border expressed as a binary variable indicating extensive border, or some or no border.

[3] Flood exposure expressed as a binary variable with "exposed" including any site exposed to one or more historical flood events since installation.

Table 3: Table of binary logistic regression models for stone-lined ditch BMP installations (n=25). Each row of the table shows results for a separate binary logistic regression model. Probability values (p) for statistically significant models are shown in bold.

Stone-lined ditch, **n = 25**			
Variable(s)$_i$[1]	P	-2 Log likelihood	Correctly classified
age	**0.004**	25.226	**84.0%**
grade	0.854	33.617	60.0%
road profile	0.172	31.786	64.0%
road orientation	0.172	31.785	64.0%

vegetated border	0.569	33.326	60.0%
flood exp	**0.001**	21.872	84.0%
age, grade	0.039	16.417	83.3%
age, flood exp	**0.003**	21.867	**84.0%**
age, flood exp, grade	0.008	21.842	84.0%
age, flood exp, grade, veg border	0.019	21.802	84.0%

[1] Indicates individual or set of explanatory variables in the model

Table 4: Table of binary logistic regression models for culverts installations (n=18). Each row of the table shows results for a separate binary logistic regression model. Probability values (p) for statistically significant models are shown in bold.

Culverts, **n = 18**			
Variable(s)$_i$[1]	P	-2 Log likelihood	Correctly classified
age	**0.029**	18.162	**77.8%**
grade	0.525	22.510	66.7%
road profile	0.368	22.105	66.7%
road orientation	0.368	22.103	66.7%
vegetated border	0.104	20.278	66.7%
flood exp	0.499	22.458	66.7%
age, veg border	**0.062**	17.367	**77.8%**
age, grade	**0.039**	16.417	**83.3%**
age, flood exp	0.086	18.002	77.8%
age, grade, flood exp	0.059	15.464	77.8%

[1] Indicates individual or set of explanatory variables in the model

Table 5: Descriptors of participating towns relevant to this study.

Town	Corinth	Huntington	Hyde Park	Waitsfield	West Windsor
Total road miles	93.74	43.96	63.45	29.67	51.28
Unpaved miles	71.99	32.78	38.84	20.22	43.64
Population[1]	1,367	1,938	2,954	1,719	1,099
Road Budget (Year)[2]	$1,076,891 (FY 2014)	$867,717 (FY 2013)	$677,707 (FY 2014)	$431,615 (CY 2013)	$876,088 (CY 2013)
Budget $ / mile	$11,488	$19,739	$10,680	$14,547	$17,084
Road Crew Salary	$147,628	$191,650	$194,153	$138,784	$155,745
Road Crew Employees[3]	3 FT 1 PT	4 FT	4 FT 1 PT	3 FT	3 FT 1 PT

[1] Data from Vermont 2010 Census of Population and Housing
[2] Refers to year of road budget provided by town administrator and assessed in this study
[3] FT = full time, PT = part time

Cost analysis

The five towns participating in in-depth interviews and cost analysis of road maintenance and BMP implementation had received funding from Better Backroads for at least one erosion control project in the past. As such, all road foremen were aware of BMP recommendations as described in the Vermont Better Backroads manual. Relevant town statistics are included in Table 5, including population as a proxy for tax base.

Results of interviews with town road foremen provide insights into how crew time and materials are used. The distribution of the road crew salaries in the five study towns, as informed by responses of road foremen to interview questions, is illustrated in Figure 12. Highlighted are the costs of non-winter, unpaved road maintenance that ranged from an estimated $47,534 in Corinth to $89,820 in Huntington. Per mile costs per town vary considerably among the five towns studied, owning primarily to differences in road length and the need to employ 3-5 crew persons per town to cover the annual workload involved in system maintenance. We focused our questions and analysis on the allocation of effort during the non-winter period, and on unpaved roads, to understand the effort devoted to maintenance and erosion control (which takes place only in the non-winter season) on this portion of the transportation network.

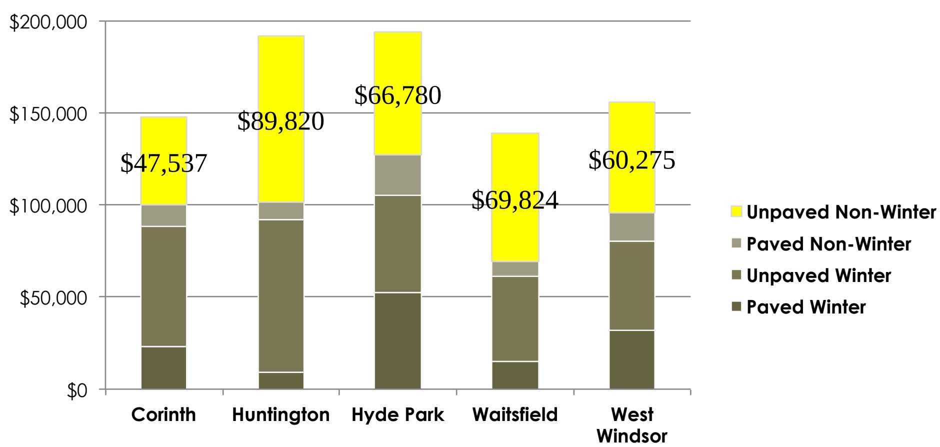


Figure 12: Distribution of road crew salary by road type and seasonal task for budget year analyzed, based on responses of road foremen to interview questions.

Table 6: Distribution of road crew salary time for unpaved roads by participating town for budget year analyzed.

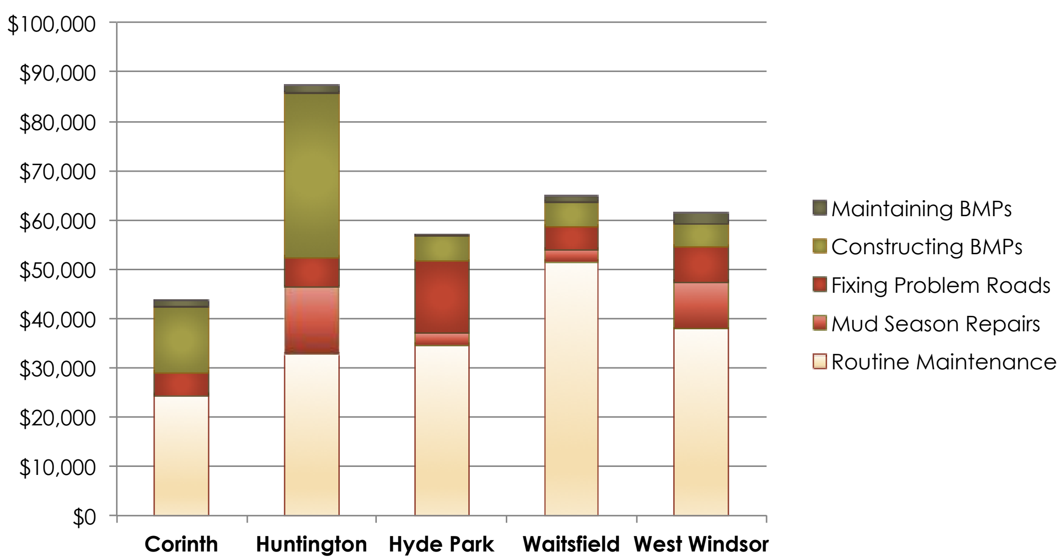
Town	Corinth	Huntington	Hyde Park	Waitsfield	West Windsor
Unpaved non-winter salary	$47,537	$89,820	$66,780	$69,824	$60,275
Unpaved miles	71.99	32.78	38.84	20.22	43.64
Salary expenditure per mile	$660	$2,740	$1,719	$3,453	$1,381

Outside the winter season, when road crews maintain the road network and can schedule erosion control work, routine maintenance occupied the largest share of time and salary expenditures, based on five key task divisions we identified from interviews (Figure 13a). Among crew time devoted to non-winter repair work, mud season repairs dominated salary expenditures in Huntington and West Windsor, and "fixing problem roads" represented the larger share of salary expnditures in Corinth, Hyde Park and Waitsfield. Salary costs for "fixing problem roads," as identified by road foremen in response to interview questions, varied from $4,654 in Corinth to $14,638 in Hyde Park for the budget year studied, or between 10% and 30% of time dedicated to non-winter unpaved road maintenance. Road crews in Corinth and Huntington spent more in crew salary for the budget year analyzed on BMP construction and maintenance than on repairs and fixes, while the opposite was true of the remaining three towns.

Materials costs distributed over the five maintenance tasks identified from the interviews are illustrated in Figure 13b. In general, material expenditures follow a pattern similar to that of road crew salaries, although some interesting patterns emerge on closer scrutiny. First, while Corinth and Huntington spent more in salaries for the budget year analyzed to construct and maintain BMPs than on repairs and fixes, materials costs for these two towns are more heavily weighted on repairs and fixes costs, suggesting that BMPs require lower material cost investments in these towns per unit time invested in road work. Second, the highest town expenditure on materials for the budget year analyzed, $207,412 in West Windsor, includes $55,687 of equipment rental, materials and trucking needed after a 2013 flood event, indicating the very high costs that many Vermont towns experience in the wake of flooding and extensive infrastructure damage.

Considered together, salary and materials costs for non-winter work on unpaved roads, the key focus of this study, ranged from $2051 per mile in Corinth to $7129 per mile in Huntington, reflecting varying needs to maintain, repair and pro-actively address erosion control measures among these towns. Although per-mile road costs are lowest in Corinth, which had the longest network of unpaved roads among the towns studied, road length alone does not control expenditures, but rather by a set of local and time-varying factors including the distribution of effort among needed tasks and the persistent need to respond to infrastructure damage while maintaining high quality rural transportation systems.

(a) Salary



(b) materials

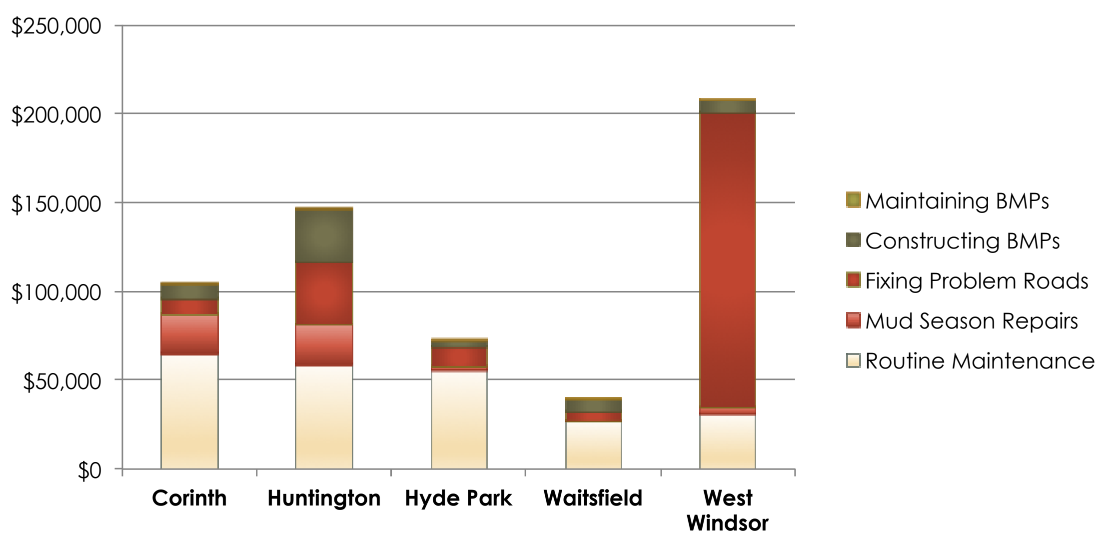


Figure 13: Distribution of (a) annual road crew salary and (b) materials on non-winter, unpaved road maintenance tasks for participating towns and budget year analyzed. Vacation salary, normally taken during the summer months, was subtracted from the total road crew salary to improve accuracy of road crew time distribution.

Table 7: Summary of costs of non-winter, unpaved road maintenance (salary + materials) for five participating towns and budget year analyzed. Cost per mile is a calculated average for the town and does not necessarily reflect true expenditures on individual road miles.

Town	Corinth	Huntington	Hyde Park	Waitsfield	West Windsor
Annual cost	$147,654	$233,680	$128,699	$104,301	$268,698
Routine Maintenance	$89,615	$92,071	$90,379	$78,390	$68,989
Repairs and Fixing Problems	$35,285	$77,082	$30,209	$12,751	$186,811
Constructing and Maintaining BMPs	$22,754	$64,527	$8,111	$13,160	$12,898
Unpaved road miles	71.99	32.78	38.84	20.22	43.64
Cost per mile	$2,051	$7,129	$3,314	$5,158	$6,157

19. Discussion

Previous work in Vermont has documented the impacts of unpaved roads on water quality, highlighting the need to address practices on this underappreciated source of water quality impairement (Wemple, 2013). Recent news reports (Remsen 2011; Schwartz 2011) of extensive road-related erosion and catastrophic road failures during record floods in Vermont in 2011 suggest that the transportation network is also highly vulnerable to storm damage and costly to repair, creating key challenges for small, rural communities. Results of this study demonstrated that the implementation of best management practices on unpaved roads significantly reduces erosion and impairments that threaten water quality of receiving waterways. Retrospective assessment of past practices showed that BMPs employed on Vermont's backroads have remained largely intact for up to nearly a decade after installation, achieving long term benefits for water quality while protecting the integrity of the road way. Costs analysis for a select set of towns showed that addressing erosion control on gravel roads, and fixing the types of problems that occur following storm events, constitute a substantial portion of the non-winter expenditures. These expenditures can be particularly straining in the wake of extreme storms. Taken together, these results suggest that a reallocation of resources from repair of damaged road segments to proactive implementation of BMPs will achieve both cost savings for towns and water quality improvements.

Although our empirical observations were limited by the set of study sites and towns we selected for study, we examined sites typical of upland settings in towns with populations, resources and road networks that span conditions of these rural settings of the state. We believe that our results should be broadly applicable across the state and useful for directing resources and policies toward back road improvements.

20. Training and outreach

Students trained:
Joanne Garton, masters degree in Ecological Planning, spring 2015, Rubenstein School of Environment and Natural Resources, University of Vermont.

Henry Schmid, undergraduate student intern, Geology major, graduated spring 2014, College of Arts and Sciences, University of Vermont.

Outreach:
Vermont Agency of Natural Resources Brown Bag Seminar series, presentation to Agency of Natural Resources and Agency of Transportation staff). March 20, 2014, Montpelier, VT.

Vermont ANR Municipal Day, presentation to town and local governance participants in day-long workshop for municipalities at Vermont Agency of Natural Resources. March 31, 2014. Montpelier, VT.

Testimony to Vermont House Transportation Committee, January 30, 2015. Montpelier, VT.

Project featured in Vermont EPSCoR ***Watershed Moments*** series, available at http://www.uvm.edu/~epscor/new02/?q=node/54&URL=http://www.uvm.edu/~epscor/jwplayer.php?video=video/wm_policy_social_master.mp4

Publications:
One planned for Journal of Environmental Management or Journal of American Water Resources Association. Expected submission summer 2015.

21. Investigator's qualifications (see attached resumes)

Wemple has extensive research experience with rural transportation networks and their hydrologic and geomorphic effects. She is PI of a New England Interstate Water Pollution Control Commission grant (awarded 2010) to quantify the contributions of rural roads to sediment and phosphorus pollution in the Lake Champlain Basin. Her faculty appointment at the University of Vermont is in Geography. She holds a secondary appointment in the Rubenstein School of Environment and Natural Resources, where she advises graduate students. Ross is a soil chemist with extensive research experience in soil nutrient and metals analysis. He manages the University of Vermont's Agricultural and Environmental Testing Laboratory, where samples for this project will be processed. His faculty appointment is in the Department of Plant and Soil Science, where he teaches and advises at the graduate and undergraduate level. He is also co-chair of the interdisciplinary undergraduate Environmental Sciences Program.

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EDUCATION:

Ph.D., 1998. Department of Forest Science, Oregon State University, Corvallis, OR.
Major: Forest Ecology; Minor: Bioresource Engineering.
Dissertation title: *Investigations of runoff production and sedimentation on forest roads*.

M.S., 1994. Department of Geosciences, Oregon State University, Corvallis, OR.
Major: Physical Geography; Minor: Geographic Techniques.
Thesis title: *Hydrologic integration of forest roads with stream networks in two basins, Western Cascades, Oregon*.

B. A., *cum laude*, 1986. University of Richmond, Richmond, VA.
Major: Economics and German.

ACADEMIC APPOINTMENTS:

Associate Professor, Department of Geography. Secondary faculty appointments in the Department of Geology and Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT. 2005-present.

Assistant Professor. Department of Geography, University of Vermont, Burlington, VT. 1999-2005.

Postdoctoral Research Associate. U.S.D.A. Forest Service, PNW Research Station, Corvallis, OR. 1999.

Graduate Research Assistant. Department of Forest Science, Oregon State University, Corvallis, OR. 1993-1998.

Graduate Teaching Assistant. Department of Geosciences, Oregon State University, Corvallis, OR. 1991-1993

PUBLICATIONS:

<u>LAST FIVE YEARS</u>

Ross, D. S. and B. C. Wemple, 2011. Soil nitrification in a large forested watershed, Ranch Brook (Vermont) mirrors patterns in smaller northeastern USA catchments. Forest Ecology and Management, 262: 1084-1093.

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ACADEMIC HISTORY

1990	Ph.D.	UVM, Soil chemistry thesis: Some aspects of the soil and water chemistry of two small watersheds in Vermont's Green Mountains
1980	M.S.	UVM, Dept. of Plant and Soil Science thesis: Toxicity of chromium to soil microorganisms and oxidation of manganese in soil.
1977	B.S.	UVM, Dept. of Plant and Soil Science
1968-1971		Middlebury College English major

EMPLOYMENT HISTORY

2007 to present	Coordinator of UVM Agricultural and Environmental Testing Laboratory (Director, 1988 to 2005)
2005 to present	Research Associate Professor, UVM Dept. of Plant & Soil Science
2003 to 2004	Research Program Coordinator (Interim) UVM Dept. of Plant & Soil Science
1996 to 2005	Research Assistant Professor, UVM Dept. of Plant & Soil Science
1996 to present	Faculty and CALS Director, Environmental Sciences Program
1991 to present	Lecturer, UVM Dept. of Plant & Soil Science

Awards

UVM College of Agriculture and Life Sciences H. W. Vogelmann Award for Excellence in Research and Scholarship, 2004.

Christine Negra (advisee) was the 2004 recipient of the Doctoral Student Scholar Award at the University of Vermont in biomedical, life, physical and applied sciences.

Membership

Soil Science Society of America
American Geophysical Union
Northeast Ecosystem Research Cooperative
Northeast Soil Monitoring Cooperative
Northeast Coordinating Committee on Soil Testing (USDA NEC-1007)

Publications in past five years (peer reviewed)

Juillerat, J.I., D.S. Ross and M.S. Banks. 2012. Mercury in litterfall and upper soil horizons in forested ecosystems in Vermont, USA. Environ. Toxicol. Chem. 31(8): 1720-1729. DOI: 10.1002/etc.1896.

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Organic phosphorus forms and transformations in Lake Champlain stream corridor soils

Basic Information

Title:	Organic phosphorus forms and transformations in Lake Champlain stream corridor soils
Project Number:	2014VT75B
Start Date:	3/1/2014
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Vermont-at-large
Research Category:	Water Quality
Focus Category:	Nutrients, Non Point Pollution, Water Quality
Descriptors:	None
Principal Investigators:	Donald Ross, Beverley Wemple

Publications

There are no publications.

Progress Report for Year One (March 1, 2014 – February 28, 2015)

1. Title. Organic phosphorus forms and transformations in Lake Champlain stream corridor soils

2. Project Type. Research

3. Focus Categories. nutrients, non-point source pollution, water quality

4. Research Category. Water Quality

5. Keywords. soil phosphorus, organic phosphorus, bioavailable phosphorus, phosphorus release, streambank erosion

6. Start Date. March 1, 2014

7. End Date. February 28, 2015

8. Principal investigators.

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Beverley C. Wemple, Associate Professor, UVM, bwemple@uvm.edu, 802-656-2074
Ph.D. candidate: Vanesa Perillo, Plant & Soil Science, UVM, vperillo@uvm.edu

9. Congressional District: Vermont-at-large

10. Abstract.

Understanding the mechanisms of bioavailable phosphorus (P) delivery from the landscape to fresh water bodies remains a key need. Recent work has shown that streambank erosion is responsible for a large portion of the sediment load entering Lake Champlain. The speciation and reactivity of the P in that sediment has not been adequately researched. Our recent work has shown that concentrations of soil test P (correlated with bioavailable P) are usually relatively low in near-stream soils and streambanks—even when high in adjacent land use. Additionally, we have shown that a large portion of the bioavailable P is in an organic form. Organic soil P is much less understood than inorganic phosphate, largely because of the difficulties involved in analysis. We propose to use a new microplate reader technique, developed by other researchers at UVM, to perform enzyme hydrolysis studies that reveal both the quantity and character of soil organic P. We will take advantage of past sampling funded by the Water Center and ongoing sampling that is supporting research on P transformations in the Missisquoi Bay. Soils adjacent to specific land uses will be analyzed for total organic P and the organic fraction then separated into reactive monoester P and nucleic (diester) P. This procedure will also be used to determine inorganic and organic P species classes in soil extractions designed to remove the bioavailable P fraction. A series of experiments will be performed to determine the release potential of both inorganic and organic P of the whole soil and the fine soil fraction that would be more likely to be transported to the lake. The soil sampling will be designed to also determine if narrower field buffer width leads to higher P in near-stream soils. This project will train a Ph.D. student and at least two undergraduate students. The results will increase our knowledge on the mechanisms and forms of bioavailable that move into the lake following the erosion of streambank soils.

11. Budget Breakdown for Year 2

Cost category	Federal	Non-Federal	Total
Salaries and wages			
- Principal Investigator	$ -	$ 28,000	$ 28,000
- Graduate Students	$ 24,480	$ -	$ 24,480
- Undergraduate Students	$ 2,500	$ -	$ 2,500
- Others: staff assistant	$ -	$ -	$ -
- Wages	$ -	$ -	
- Total Salaries and Wages	$ 26,980	$ 28,000	$ 54,980
Finge Benefits	$ 1,738	$ 11,984	$ 13,722
Supplies	$ 3,172	$ -	$ 3,172
Equipment	$ -	$ -	$ -
Services or Consultants	$ -	$ -	$ -
Travel	$ 2,000	$ -	$ 2,000
Other Direct Costs (tuition)	$ 6,110	$ -	$ 6,110
Total Direct Costs	$ 40,000	$ 39,984	$ 79,984
Indirect costs on federal share	XXXXXX	$ 21,000	$ 21,000
Indirect cos ton non-federal share	XXXXXX	$ 20,992	$ 20,992
Total Estimated Costs	$ 40,000	$ 81,976	$ 121,976
Total costs at Center campus	$ 40,000	$ 81,976	$ 121,976
Total costs at other University	$ -	$ -	$ -

12. Budget Justification

Salaries and Wages: The stipend for the graduate student ($24,480) includes a 2% raise from the current level. Salary cost share will be provided by coPIs Ross and Wemple at approximately 15% each ($28,000). The $2,500 in wages is to hire undergraduate students during the fall and spring semesters to assist with sample processing and analysis. RACC interns are only available during the summer. The hourly rate is set between $10 and $12 depending on experience and approximately 230 hours of labor will be used.

Fringe Benefits: Fringe benefits 7.1% for the graduate student stipend. The rate for Ross and Wemple's cost share was calculated at 42.8% (prorating FY15 and FY16 rates). No fringe is charged on students taking classes.

Supplies: Supplies covers the cost of enzymatic analysis, 250 samples at $10 each, and $672 for lab supplies and reagents ($100 for dissolved oxygen membranes, $100 for ferrous iron reagents, $200 for soluble reactive P tests and $272 for miscellaneous consumables that includes centrifuge tubes, microplates and pipette tips). The bulk of the cost for the enzymatic analysis is the enzymes themselves.

Travel: $1000 is budgeted for 30 trips to field sites by the PhD student and the coPIs of 60 roundtrip miles each at the current UVM mileage rate of $0.55. Another $1000 is budgeted to partially cover expenses for the PhD student to attend one national scientific meeting.

Other Direct Costs: Last year's budgeted amount for graduate student salary was actually separated into a stipend and tuition in order to comply with new UVM policy. The proposed budged for Year 2 includes a tuition estimate for one semester based on a projection supplied by the Graduate College. The other semester will be provided by PI Ross's USDA Hatch support.

Indirect: The normal indirect rate for UVM is 52.5%.

13. Organic phosphorus forms and transformations in Lake Champlain stream corridor soils

14. Statement of regional or State water problem.

It is now clear that streambank erosion can contribute a large portion of the sediment load delivered to Lake Champlain (e.g. Langendoen et al. 2012). Phosphorus, in various forms, is associated with this sediment. There are three relatively unknown factors associated with streambank erosion: i) how much P is released (or sorbed) by the sediment when it enters the stream channel, ii) how much of the sediment is delivered to the lake and iii) how much of the sediment-bound P will become bioavailable once it reaches the lake. We have been measuring soil P in a large number of Lake Champlain stream corridor soils with prior funding from the Water Center and other sources (Lewis Creek, LaPlatte River, Allen Brook, Alder Brook, Indian Brook, Mad River, Rugg Brook, Black Creek, Missisquoi River and Rock River). We found a relatively narrow range of *average* total soil P in each watershed with somewhat more variability in 'available' (soil test) P and the degree of phosphorus saturation (DPS). Two findings are relevant to this proposal: i) overall, available P tended to be low in streambank soils (Young et al. 2012) and ii) a large portion of this available P was found to be in the organic form (Young et al. 2013). In order to understand the bioavailability of riparian soil P, we need a better understanding of the nature of the organic P in these soils, and new tools are available. The proposed work will determine the fraction and class of organic P in streambank soils, investigate how this P transforms within the stream and, making some assumptions about the particle size transported, investigate how this sediment P will transform in the lake environment.

It is also clear that buffers between various land uses and the streambank edge can be effective in avoiding or slowing overland runoff of sediment and associated nutrients. Our recent work (see below) has shown that both total and available P can be much lower in streambank soils that have a buffer from agricultural fields in corn silage production. However, we have also found high P in streambank soils in other types of agricultural fields where no buffer exists. To our knowledge, this buffer effect on streambank soil P concentrations has not been documented. Most studies have examined effects on direct runoff. If buffers help maintain lower total and available P, then there is a direct effect on the amount and bioavailability of P delivered to the lake via streambank erosion. While buffers are mandated for some types of agricultural operations (and are recommended as best practice for others), they are not universally adopted. To provide more data on this effect, the sampling design for the study of organic P in streambank soils will incorporate different land uses and buffer widths.

15. Statement of results or benefits.

Progress to date:

A Ph.D. student, Vanesa Perillo, was recruited and started at UVM in the fall semester of 2014. Ms. Perillo has a strong background in biochemistry and international experience in lake studies. Analysis of organic P fractions is underway, utilizing the enzymatic microplate technique developed by Johnson and Hill (2010) and refined by C. Giles (former UVM RACC postdoc, personal communication). Example results from this procedure (Fig. 1) show the range in results from an agricultural field quite high in total P, reflecting intensive management, to a riparian soil in a forest setting that had a total P content close to

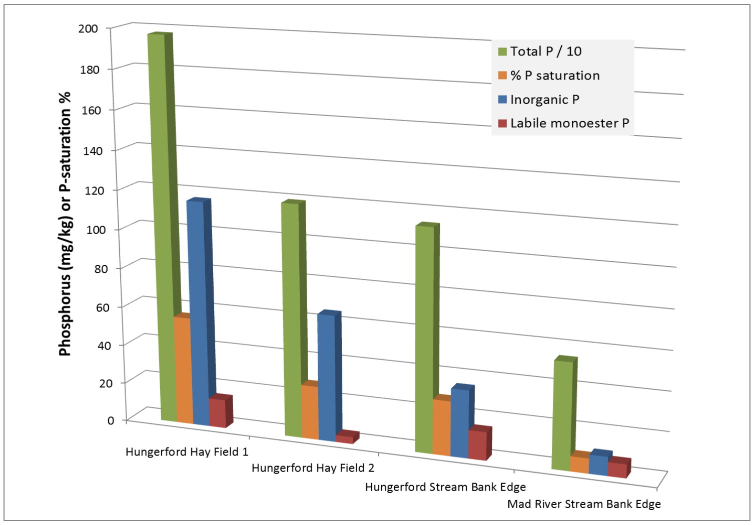


Figure 1. Total P, P saturation and inorganic vs. labile monoester P in NaOH/EDTA extractions. These example soils were taken from the 0-15 cm depth of two active agricultural fields in the Missisquoi Watershed and 1 m from the stream bank in the Missisquoi and Winooski watersheds.

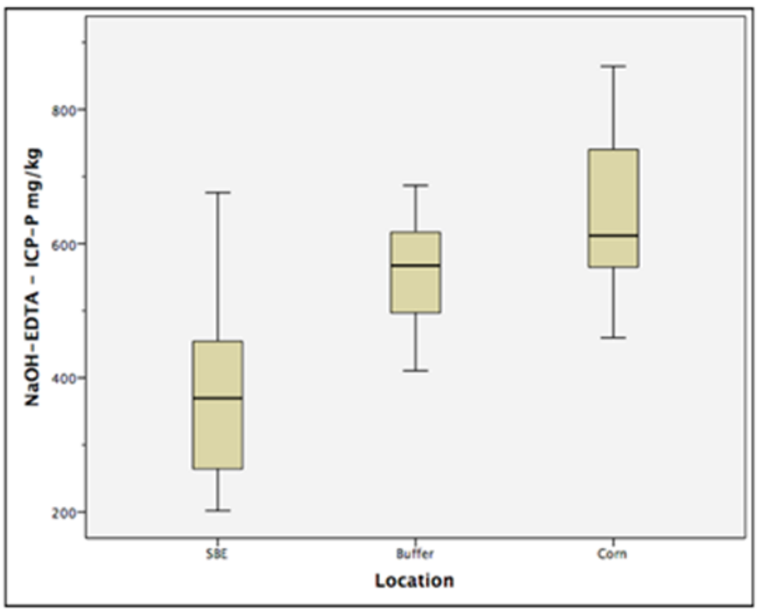


Figure 2. Total P in NaOH/EDTA extractions used to extract organic P. SBE is stream bank edge. Error bars represent ± 2 SE.

background concentration. The high-P soil also had a high P saturation (calculated from the P, Al and Fe found in an acid ammonium oxalate extraction). The automated microplate assays on NaOH/EDTA extractions showed that a high proportion of P in the P-enriched soil was inorganic (phosphate). Labile monoester P includes a range of organic P compounds and represents a soil fraction that should be considered bioavailable in transported sediment. As expected, variability in this organic fraction did not follow the pattern of inorganic P. At lower overall total P concentrations, the labile monoester P is a much higher proportion of extractable P. High-P soils have been enriched by both manure- and fertilizer-P additions. Preliminary data suggest that the majority of added P is retained as inorganic P. Near-stream and streambank soils are usually lower in total P (Fig. 2) and organic P is a more significant component of this total (Fig. 3). Our ongoing work will enhance our understanding of the reactivity of this P fraction.

The effect of land use can be seen when averaging the results by land use (Figs. 2 and 3). These graphs more clearly show the phenomenon discussed above. Total NaOH-EDTA-extractable P (somewhat less than total P by acid digestion) was clearly higher in corn fields in the Hungerford Brook watershed than in nearby streambank soils, while total P in the buffer strip between the two land uses was somewhere in the middle. The variability appeared to be higher in the streambank soils, probably reflecting variable influence of adjacent land use practices. Similar to the total extracted P, inorganic P was higher in the agricultural land use but labile monoester-P, probably the main form of organic P in these soils, was actually higher in the streambanks (Fig. 3).

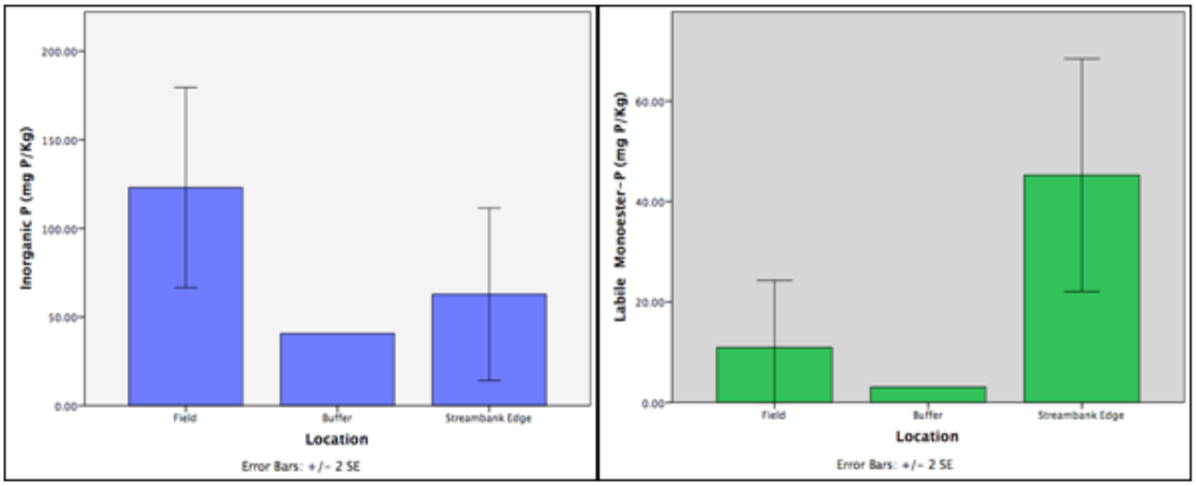


Figure 3. Inorganic P (orthophosphate) and labile monoester-P in NaOH/EDTA extractions from soil samples taken in the Hungerford Brook watershed. SBE is stream bank edge. Error bars represent ± 2 SE.

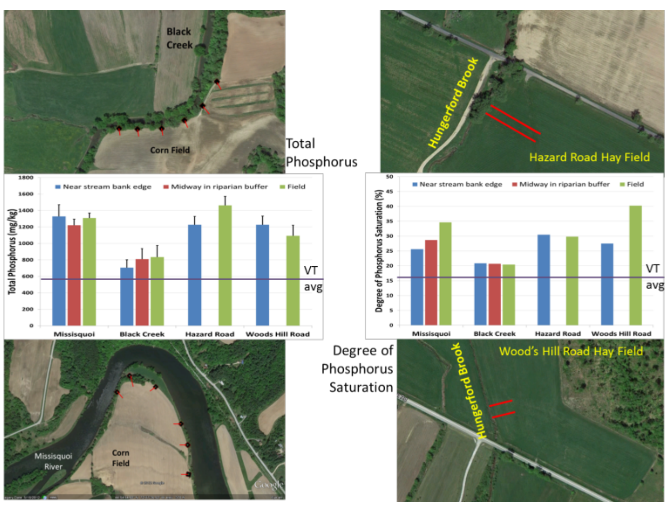


Figure 4. Total P (left) and P saturation (right) in four agricultural fields in the Missisquoi Watershed. The average for Vermont soils is taken from data in Figure 5. Maps show the location of sampling transects.

In addition to the P enzyme work in progress, we have completed and compiled analyses of total soil P and P saturation in soils along transects from both the Missisquoi (Fig. 4) and Winooski watersheds. Relative to findings in less agriculturally-intensive watersheds (Fig. 5), the transect soils in the Missisquoi have elevated concentrations of total P and greater P saturation. These high concentrations appear to reflect a history of P additions and likely create the potential for greater P transport into the lake. The total concentration of P appears to have less variation with transect position than soil test P (Fig. 5), likely the legacy of pre-buffer P additions. An interesting question that these results pose is whether or not there is a difference in the bioavailability of P from sediments originating from 'aged' P applications (e.g. current buffer strips that were once active managed) and the bioavailability of more recently added P. This will be important in predicting the eventual release of P from streambank erosion in these locations.

In this and previous Water Center funded projects, we have been constructing a database on phosphorus in Vermont soils. Working with the ongoing EPSCoR RACC project, High School teams from around Vermont have been sampling riparian soils and submitting them to Ross's laboratory for analysis. Both those samples and samples from four Chittenden County stream corridors showed a mean total P of about 600 mg/kg. Samples from all depths along transects in Missisquoi Watershed corn fields had a mean of

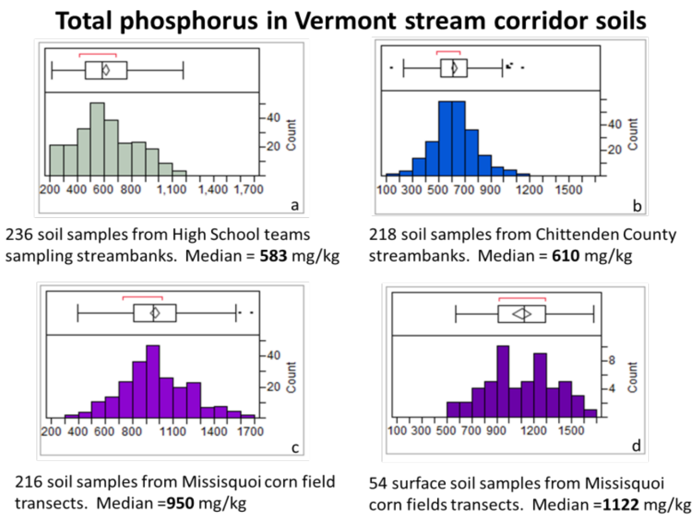


Figure 5. Distribution of total phosphorus in samples collected by RACC High School teams (upper left), previous Water Center project (upper right), ongoing research in the Missisquoi Watershed (all depths, lower left; 0-15 cm, lower right)

950 mg/kg and those from the surface had a mean of over 1100 mg/kg. These data show the impact of fertilizer and manure P additions on the total concentration of P in these soils. Our past research (Young et al. 2012) showed some variation in total P with soil texture but the differences shown in Fig. 4 do not appear to be related to differences in soil particle size. Continued soil sampling and analysis of a range of P forms should validate our initial conclusion that past agricultural practices have created relatively P-rich soils. Once transformed into submerged sediment, cycling of P in these, and less enriched soils, will be the focus of the second year of this study.

The benefits of the study include:

1. A better understanding of the forms (speciation) of organic phosphorus in streambank soils of the Lake Champlain Basin.
2. A better understanding of the P release potential of these soils once eroded, both in the stream channel and in lake sediments.
3. Determination of the effect of buffer strips on the P concentration and bioavailability in associated streambank soils.

The first two will aid in our mechanistic understanding of the delivery of bioavailable P to the water column in Lake Champlain. This should help both in mechanistic and predictive modeling. The research into buffer strip effectiveness should provide supporting evidence for greater adoption of this practice.

16. Nature, scope, and objectives of the project, including a timeline of activities.

Ross and Wemple are currently participating faculty in the NSF-funded VT EPSCoR project ‘Research on Adaptation to Climate Change’ (RACC). While we have no graduate student support allocated through this project, we do have access to undergraduate interns sponsored by the VT EPSCoR Center for Workforce Development and Diversity (CWDD). For the past few summers, these interns have been sampling stream corridor soils in both the Missisquoi and Winooski watersheds in support of other RACC research into streambank stability. The interns have been providing soil characterization that includes total P, soil test P, DPS, inorganic N and particle size. The RACC work on detailed speciation of P, including organic forms, is taking place primarily in Missisquoi Bay. Our study watersheds will initially be Hungerford Brook, a subwatershed in the Missisquoi network, and the Mad River watershed in the Winooski system. Our USGS Water Center work will continue to take advantage of the sampling and basic soil analyses provided by CWDD interns for these other projects.

Objectives:

1. **Determine the organic phosphorus fraction and speciation of stream corridor soils.** How much of the soils' total and 'available' P is in the organic form and what class of organic compounds is it in? We will use the new microplate method for enzymatic analysis developed at UVM (Johnson and Hill 2010).

2. **Determine the transformation rate of the organic phosphorus fraction to inorganic P when the soil is submerged.** How bioavailable is this P fraction? This will be assessed both in whole soil and in the fine fraction that is more likely to be transported to the lake.

3. **Determine the effect of stream buffer width and land-use on phosphorus fractions in streambank soils.** Does the width of the buffer relate to the build-up of P in the near-stream soils? We will incorporate this objective into the sampling design used to obtain soil samples for the first two objectives.

Timeline:

Fall 2014	Begin incubation studies with freshly collected samples, conduct soil enzymatic analysis for organic P fractions. Recruit undergraduate assistant for laboratory work.
Winter 2015	Continue enzymatic analysis with different extraction techniques.
Spring 2015	Analyze existing data on buffer widths and select additional sampling sites.
Summer 2015	With the help of CWDD interns, sample transects designed to test buffer width effectiveness.
Fall 2015	Conduct second series of incubation studies with freshly collected soils from contrasting land use.
Winter 2016	Prepare final report.

17. Methods, procedures, and facilities.

Transect sampling and analysis: Soil samples will be obtained with the assistance of CWDD interns using the sampling design detailed below (Fig. 6). The 2015 sampling will expand beyond Hungerford Brook into the greater Missisquoi and Winooski watersheds and focus on buffer width in active agricultural land use (both corn and hay). Samples will be processed by the interns and analyzed in UVM's Agricultural and Environmental Testing Lab under the supervision of Joel Tilley. CoPI Ross is director of the facility and immediate supervisor for Tilley. This analysis will be funded through the

RACC project and will include total P, soil test P, DPS (ratio of oxalate-extractable P to Al + Fe) and particle size distribution. The PhD student will continue processing and analyzing the soils for organic P fractions by the method of Johnson and Hill (2010). For total organic P, the procedure involves extraction with NaOH/EDTA and hydrolysis with phosphatase from two different sources (potato and wheat germ) and nuclease P1 from *Penicillium citrinum*. The method utilizes microplate technology and allows a high throughput. The enzymes separate the extracted P into inorganic, labile monoesters and nucleic acids. The monoester fraction includes phytate-like compounds, thought to be a dominant fraction of organic P in many soils. This method has recently been validated by Giles et al. (2014) on sediment samples from Lake Champlain. In addition to the traditional NaOH/EDTA extract, use of the enzymatic approach with weaker extractions, similar to Young et al. (2013) will be investigated. We will compare results from water extracts, weak salt (0.01 *M* $CaCl_2$) and Modified Morgans soil test extraction (pH 4.8 ammonium acetate, 1.25 *M* acetate). The automated enzyme method will also be used in P release studies outlined below.

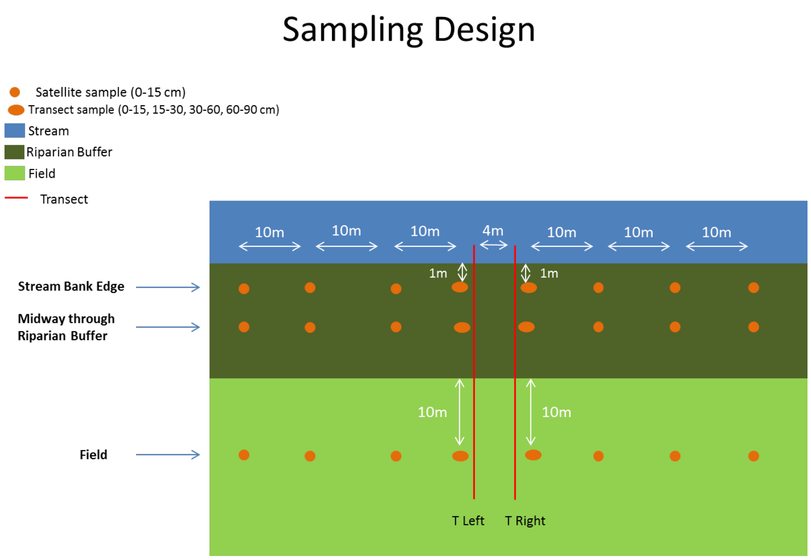


Figure 6. Schematic of soil sampling design to be used in this study. Soils will be sampled in increments to 90 cm along the two transects but only to 15 cm along the 'satellite' samples. The latter are designed to assess variability.

Release or sorption of P from eroding soils: Using soil characterization results from past sampling, we will select 12 locations that provide a contrast in total P, soil test P and soil texture (particle size distribution). Just prior to experimentation, fresh soil samples will be obtained from these sites, sieved through 4 mm screen to remove coarse fragments and kept moist to avoid potential drying-induced changes in P behavior. Three sets of replicated experiments will be conducted over 12-week incubations (or longer depending on response). The first two will use whole soil samples incubated in stream water obtained from the Missisquoi River. One experiment will maintain oxygenated conditions by simple aeration with aquarium pumps and the other will allow anaerobic conditions to develop (similar to experiments performed by Young and Ross (2001)). The third experiment will use the < 0.05 mm fraction (silt + clay) of the soil and lake water from Missisquoi Bay with no aeration. Separation will be done by sonication and sedimentation of the sand. All incubations will be performed in the dark to mimic lake and river sediment conditions and to avoid confounding factors of light-induced growth. During the incubation, the water column will be monitored for changes in dissolved oxygen, reduced iron and soluble phosphorus species (fractionated enzymatically as described above). After the incubation, each microcosm will be spiked with inorganic P to double the current total soluble P concentration and again monitored for changes for an additional 4 weeks. The initial incubations will reveal the P release potential of these soils and provide speciation information on solubilized P. The spiking experiment will measure the potential of the soils to remove external P inputs from the water column. In the second year of the study, these experiments will be repeated with samples taken from different land uses (row crops, meadow, forest) but with similar other properties (texture and soil test P). This design will allow comparison of potential P release from different land uses. All samples used in these incubations will have the full suite of characterization tests performed as described above. The three experiments described will be run concurrently to avoid any possible storage-related changes in soil P fractions.

Buffer width: This work will utilize sampling from 2012 and 2013 in addition to transects established during this study. All sites are georeferenced and GIS analysis will be used to standardize buffer width measurements and confirm land-use at the older sampling sites. As mentioned above, the 2015 sampling will intentionally be designed to provide a range of buffer width in active agricultural fields. The analysis will consider buffer width, a range of soil P measurements of the near-stream soils, the differences in these measurements between soils from the adjacent land use and the near stream, and the type of land use itself. This database will be built using the sampling for measuring organic P fractions, not as a stand-alone experiment. If early trends are confirmed, the results will provide further valuable evidence on the usefulness of riparian buffers.

Statistical analyses: If the necessary assumptions are met, simple analysis of variance will be used to determine if there are significant differences in soil properties over the field-buffer-streambank transect and among the four depth increments. Soil properties will include those measured during the characterization phase and different estimates of organic P fractions. In the P release studies, time-series analysis will be employed to determine if there are significant changes in P forms. Two approaches will be used to analyze data in the buffer width study, a multivariate approach (NMS) and simple regression analysis of width vs. change in soil P characteristics (again after testing assumptions, e.g. normal distribution of residuals and even variance).

18. Related Research.

Phosphorus (P) has long been recognized as the primary limiting nutrient for algal growth in fresh water systems. Along with an increase in P loading, Lake Champlain has seen an increase in algal blooms during summer months, with eutrophication recorded as early as 1977 (Budd and Meals, 1994).The majority of P from the landscape is sediment bound (e.g. Loeb, 2008; Sharpley, 1995). Streambank erosion has been identified as a potentially significant source of sediment and P into Lake Champlain and elsewhere, contributing 17-93% of total suspended sediments (TSS) to collecting water bodies (Langendoen et al. 2012, Sekely 2002). In Chittenden County, DeWolfe et al. (2004) found streambank erosion to be highly variable in its contribution to suspended sediment, ranging from the least to the greatest single contributor. Recent work in the Missiquoi watershed estimated 36% of both the sediment load and total P delivered to Missiquoi Bay were from streambanks (Langendoen et al. 2012). While streambank erosion represents a major source of sediment and associated P into hydrologic networks (McDowell et al., 2002; Kalma and Ulmer, 2003; DeWolfe et al., 2004), the characterization of this P is largely unknown, particularly in regard to the fraction of P that will become bioavailable over time.

Soil organic P is comprised of a wide range of compounds with differing degrees of bioavailability, with a range from 29-65% of total soil P (Harrsion et al., 2002). Inositol hexaphosphates are a specific class of organic P compounds with a 6-carbon (inositol) ring and between 1-6 phosphate groups attached through monoester bonds. Phytate, myo-inositol hexakisphosphate, can be a large portion of the soil's organic P, inherited from plant decomposition products (Raboy, 2007). Manure additions can result in phytate additional accumulation in the soil (Turner, 2002). It can be strongly bound by soil constituents and was once considered relatively immobile in soils. Recent work has shown relatively high loss of phytate from manured soils (Hill and Cade-Menun 2009), pointing out the need for more research. Nucleic acids also contain P, usually in the diester form. The decomposition products of plant, animal and microbial residues therefore contain a sizeable component of organic P. A number of enzymes, produced by plant roots and microorganisms, can hydrolyze the different types of ester bonds. Particular combinations of purified enzymes have been used to analyze soils and group organic P into broad classes. Hydrolyzed organic P is converted to inorganic phosphate, which is easily quantified with molybdate-based colorimetric assays. Traditionally, identification of organic P is performed with NMR techniques and the difficulty and expense of these procedures has limited the amount of available data. The new enzymatic methods do not enable as detailed a characterization but offer the possibility of obtaining sufficient numbers of data in order to observe trends and transformations across the landscape.

Our initial Water Center-funded work focused soley on near-stream soils (within 1 m of banks) and we found unexpectedly low concentrations of soil test (Modified Morgans extract) phosphorus (Young et al. 2012, 2013, Ishee 2011). This soil test extraction has been found to corrleate well with other measures of bioavailable P (Magdoff et al. 1999). Our more recent work, associated with the RACC project, has extended the soil sampling into adjacent land use, with a sampling scheme similar that shown above under methods (Fig. 6). This sampling, by CWDD interns, was performed in active silage corn fields in the Missisquoi watershed in 2012 (240 samples) and in a variety of land uses in the Mad River and Hungerford Brook watersheds in 2013 (440 samples). Again, streambank soiltest P was relatively low but there was a clear trend towards higher P through the buffer into the adjacent land-use (Fig. 7).

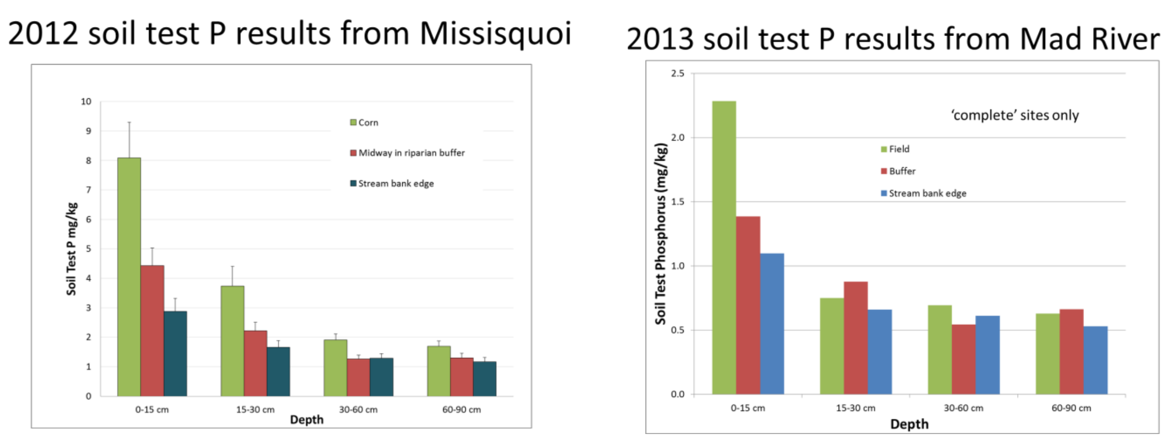
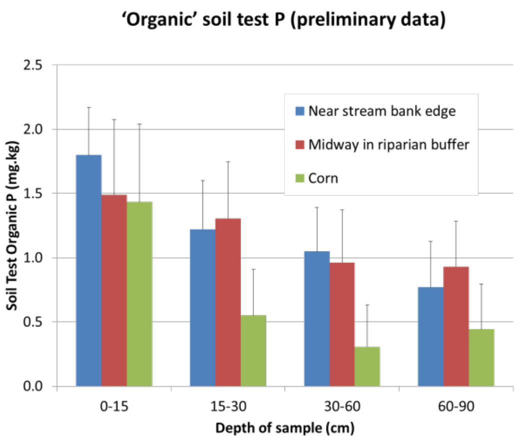


Figure 7. Soil test phosphorus (Modified Morgans extract) at sites along the Missiquoi River and Black Creek (left) and the Mad River (right). Note the different y axis ranges.

The amount of organic P in the soil test extract can be estimated by the difference between the total amount of P in solution (by ICP-AES) and the amount of phosphate (colorimetrically by molybdate reaction). It is interesting that there was a trend towards higher concentrations of organic P in the near-stream soils even though the overall concentration of soil test P was lower (Fig. 8a). These streambank soils receive little in the way of inorganic P fertilization and apparently have a different speciation dynamic than soils in active agriculture. This dominance of organic P in the available soil P fraction was also shown in our earlier work with simple water extractions of near-stream soils (Fig. 8b, from Young et al., 2012). The data collected for Fig 8b was done using manual enzymatic methods. We are proposing to do similar work but with the automated method of Johnson and Hill (2010). These methods have been correlated with the more precise benchmark method using ^{31}P NMR (e.g. Fig. 9a from Young et al., 2012). The NMR method is considered definitive but enzymatic methods have been developed to allow adequate sample throughput for studies such as the one we are proposing.



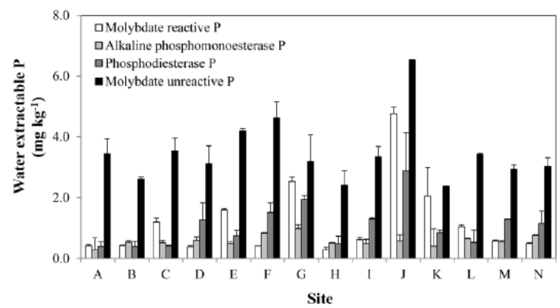


Fig. 3. Concentrations of water-extractable molybdate reactive phosphorus (MRP), molybdate unreactive phosphorus (MUP), MUP phosphorus hydrolyzed by alkaline phosphomonoesterase addition (alkaline phosphomoesterase-P), and MUP hydrolyzed by the addition of phosphodiesterase (phosphodiesterase-P).

Figure 8. (a, left) Organic P concentration in the Modified Morgans soil test extract estimated by the difference between total P and molybdate-reactive P (inorganic phosphate). (b, right) Enzyme derived estimate of organic P in water extracts of 14 Lake Champlain Basin near-stream soils (from Young et al. 2013).

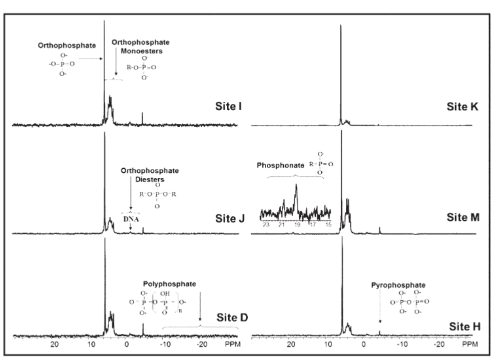


Fig. 1. Phosphorus-31 nuclear magnetic resonance spectra of NaOH-EDTA extracts for selected soils, showing peaks and corresponding P compounds. Spectra are scaled to the orthophosphate peaks. Sites I, J, K, and M are poorly drained; Sites D and H are moderately well-drained.

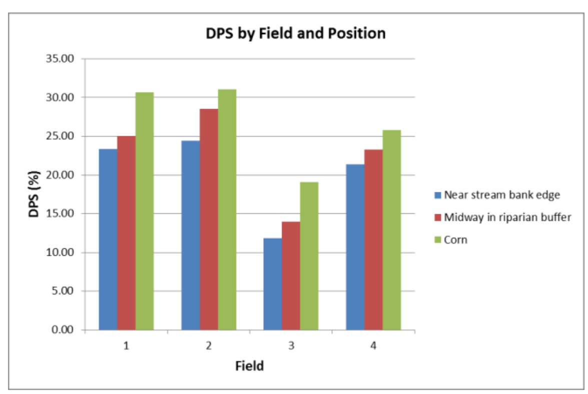


Figure 9. (a, left) ^{31}P NMR spectra of 6 soils from Basin near-stream soils showing the variety of organic P compounds present (from Young et al. 2013). (b, right) The degree of phosphorus saturation in transects from 4 corn fields in the Missisquoi Watershed (data generated by Miriam Howland, an exchange student from Cardiff Univ.).

In addition to being relatively low in soil test P, near-stream soils have also been found low in the degree of phosphorus saturation (DPS) measured by the ammonium oxalate method of

Hooda et al. (2000). The test extracts the poorly crystalline fraction of soil Al and Fe, which has been shown to strongly sorb phosphate. The quantity of extractable P relative to Al and Fe is the DPS. We have found that near-stream soils along Lake Champlain Basin river corridors have DPS in the range of 15-30%. Again, as might be expected, DPS is lower in near-stream soils than soils in adjacent active agriculture (Fig. 9b). These results suggest that stream bank soils could potentially sorb P from the water column once eroded into the streams. Poirier et al. (2012) showed that the fine fraction of soil transport from agricultural fields (in the Pike River watershed that drains in Missisquoi Bay) are enriched in P and likely contribute proportionally more to eutrophication because they can be transported. It is unknown if enrichment is found in the fine fraction of near-stream soils that have not received P additions in fertilizer or manure. More work is needed to determine if this fraction is actually a source or sink for P, once eroded into the stream network.

There is a voluminous amount of literature on riparian buffer strips (see Hoffman et al. (2009) for a recent review). Most of the work has focused on these buffers as filters for overland flow. From the perspective of the fate of eroded streambank soils, the width of a buffer may influence the degree of P buildup from the adjacent land use. In our work in the Mad River during the summer of 2013, we found situations where the width of the buffer was too narrow to sample our standard three points of field, buffer and near-stream. In these situations, the near-stream soils were elevated in soil P when the field itself was high (Fig. 10). These observations are quite preliminary but the design of our study will allow us to investigate this possible relationship while also investigate the behavior of S organic P.

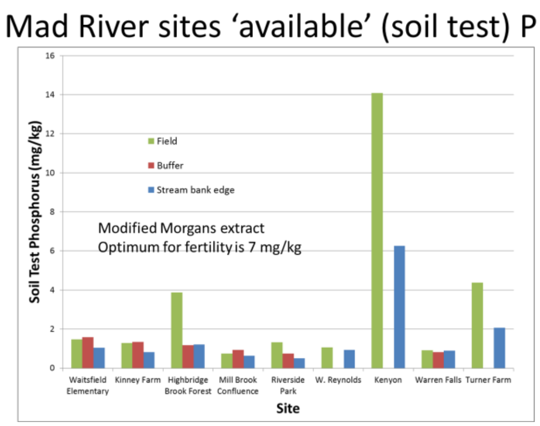
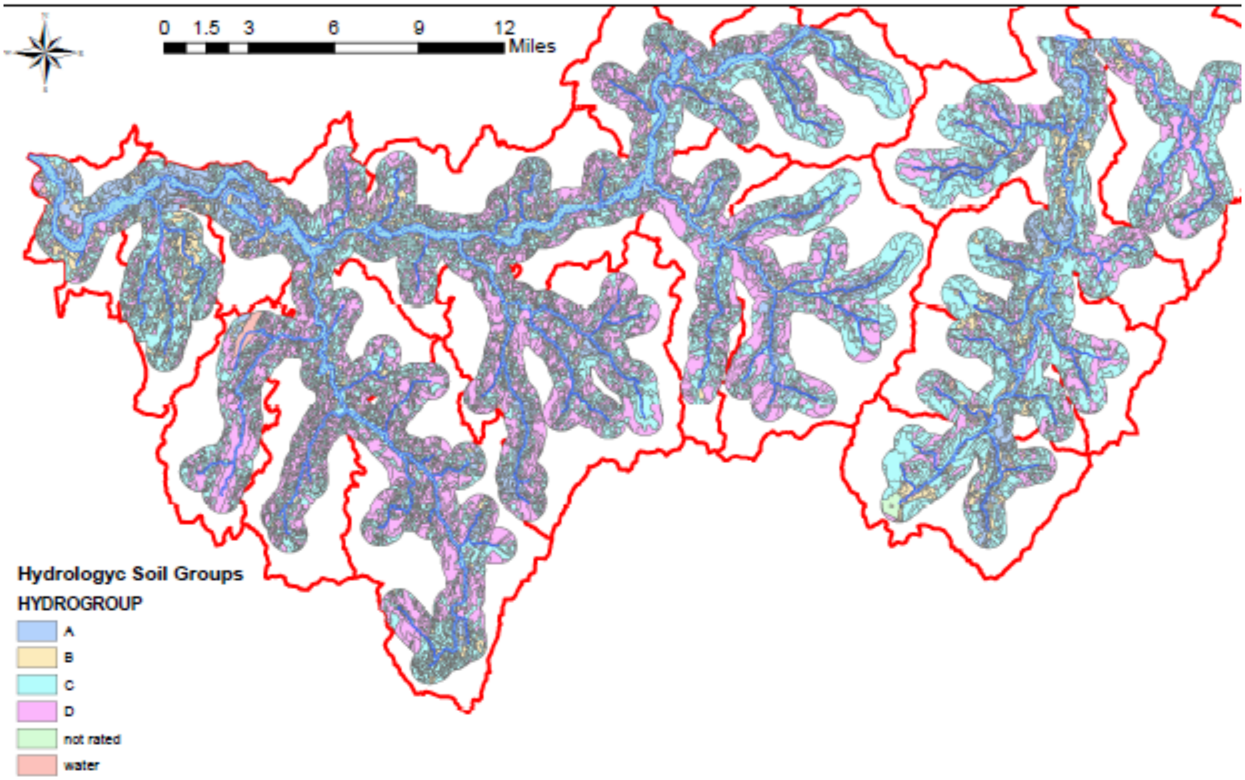


Figure 10. Left, soil test P at nine different stream study sites in the Mad River, sampled in 2013. The sites missing red bars had effectively no buffer. Right, aerial view of narrow buffer on an agricultural field with high soil-test P.

Activities in Year Two.

Activities in year two will follow the plan outlined above. The sampling plan has been refined to encompass the major land use types found along the corridor of the Missisquoi River and its tributaries. Each land use/ land cover (LULC) is being further subdivided into the five hydrologic soil groups. Initial GIS analysis has provided maps on the distribution of these LULC-soil group combinations (Fig. 11) and the absolute and relative amounts of each (Fig. 12). Initial field verification and sampling is underway. Early sampling this field season will also test the effect of soil drying and storage time on the concentrations of the labile organic P forms.



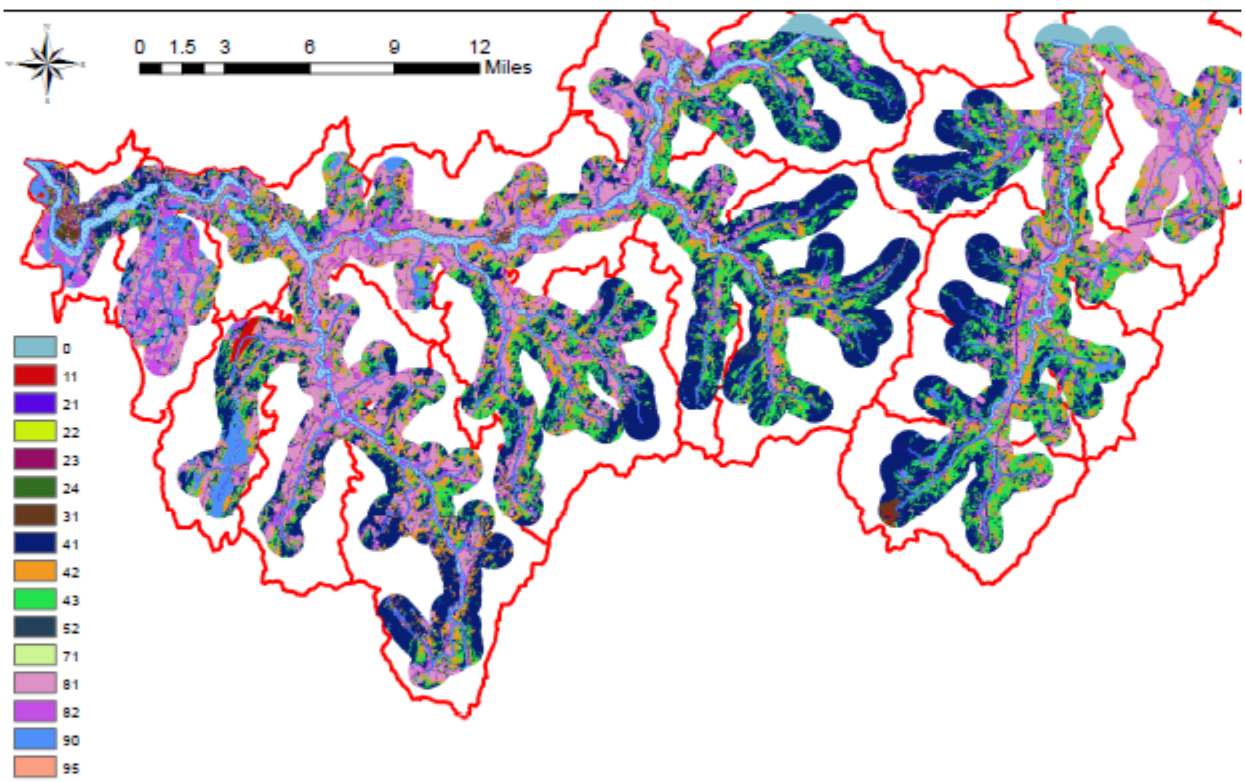


Figure 11. Map of the stream corridor of the Missisquoi River and its major tributaries showing the hydrologic soil group (top) and the land use / land cover classification (bottom).

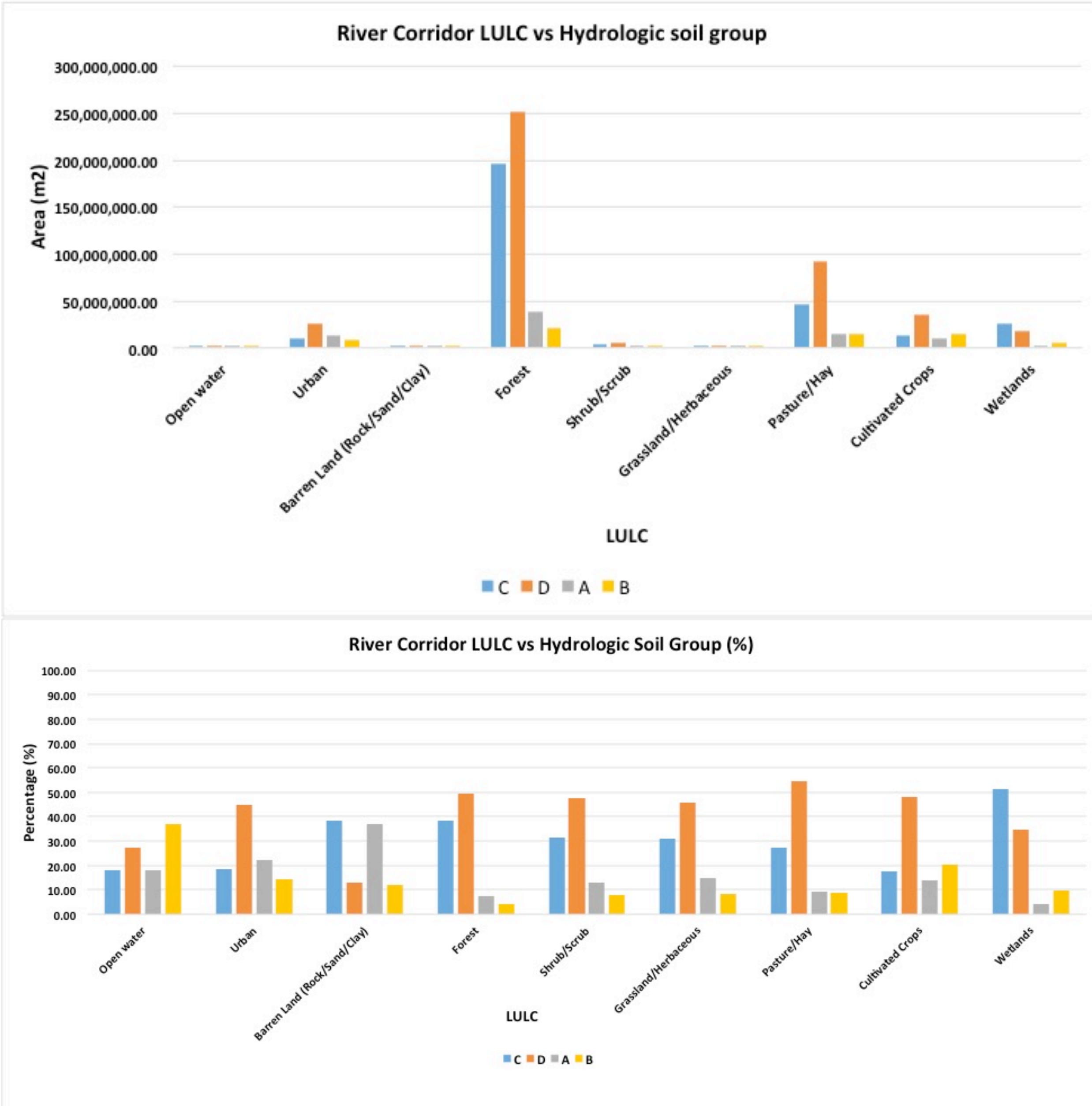


Figure 12. Area of the Missisquoi River corridor in each land use / land cover subdivided by soil hydrologic group (top) and percent of each hydrologic soil group with each land use / land cover classification (bottom).

19. Training potential.

One Ph.D. student will be supervised jointly by the coPIs and will receive training in all aspects of the proposed research and associated reporting. At least two undergraduate students will be trained in both field sampling and laboratory techniques. We anticipate these will be Environmental Sciences majors and will likely also do internships for credit in their major.

Publications / Outreach / Education.

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An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish

Basic Information

Title:	An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish
Project Number:	2014VT76B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	Vermont-at-large
Research Category:	Biological Sciences
Focus Category:	Conservation, Ecology, None
Descriptors:	None
Principal Investigators:	J Ellen Marsden, Jason Stockwell

Publications

There are no publications.

Title: An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish

Project Type: Research

Focus Categories: Conservation, Ecology

Research Category: Biological Sciences

Keywords: aquatic habitat fragmentation, migration

Start Date: March 1, 2014

End Date: February 28, 2015

Principal investigators: J. Ellen Marsden, Professor, University of Vermont, ellen.marsden@uvm.edu
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Congressional District: Vermont-at-large

Abstract: The effects of habitat fragmentation on individual movements and population structure have been widely studied in terrestrial habitats and riverine systems, but there are few examples of large-scale fragmentation of lake habitats. Lake Champlain is an unusual system in which separate basins were isolated from the main lake by the construction of several causeways in the 1800s. Openings in these causeways are narrow and shallow, limiting access for coldwater species between basins to the winter months when surface waters are cold. As a result, fish populations may be fragmented, and movement of sub-populations may be largely restricted to basins where food or seasonal habitat are sub-optimal. We propose to study year-round movements of fish between the four major basins of Lake Champlain – the Main Lake, Malletts Bay, Inland Sea, and Missisquoi Bay – using an acoustic telemetry array focused at the causeways separating the basins. Acoustic telemetry allows passive detection of tagged fish that move within the range (1.25 km radius) of receivers; tag life is up to three years so data will be collected from individual fish over multiple seasons and years. Our objectives are to (1) establish an acoustic receiver array in Lake Champlain and provide infrastructure to support multiple studies of fish movements, and (2) determine the range of individual lake whitefish movements in Lake Champlain with particular emphasis on movements in relation to barriers (causeways) that fragment the lake. In total, between this study and the non-federal matching funds, 28 receivers will be deployed and 111 fish will be tagged. In addition to this project, the receiver array will be useful for a wide array of future studies on fish movements.

An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish

Statement of Problem

Large lakes are complex, three-dimensional systems of habitats, ranging from warm, shallow, productive nearshore zones to deep, cold, oligotrophic zones (Hutchinson 1967). Some fish species may spend their entire lives in one area; more commonly, however, fish undergo ontogenetic, seasonal, or daily migrations in search of food, shelter, or spawning sites. Thus the population health of many species depends on the availability and quality of two or more disparate habitats and their connectivity (e.g., Jones et al. 2003). Human activities that alter habitat quality or connectivity may have significant negative effects on fish abundance and distribution. A lack of understanding of fish movements, population sub-structuring, and habitat requirements may leave management vulnerable to taking actions that could inadvertently reduce survival, reproduction, or distribution of native species.

Lake Champlain offers a novel opportunity to study the consequences of whole-lake restructuring on the movements and population restructuring of fish species. Since the early 1800s, construction of ten major causeways has progressively fragmented the lake into a set of relatively isolated regions (Inland Sea, Mallet's Bay, Carry Bay, the Gut, and the northern section of the Northwest Arm; Fig. 1). These causeways range from to 300 m to 5.25 km long; all have openings to allow boat traffic through them, but these openings are shallow (approx.. 2-3 m deep) and narrow (24 to 250 m wide; Marsden and Langdon 2012). While most of the causeways were built with openings in them, the Sandbar causeway that separates the Inland Sea from Malletts Bay did not have an opening until 1907, 57 years after its construction. The combination of reduced connectivity between bays, and resulting changes in water movement and nutrient flow, may have resulted in population sub-structuring of several species, including rainbow smelt (*Osmerus mordax*), walleye (*Sander vitreus*), and lake whitefish (*Coregonus clupeaformis)*. For example, a 20-year monitoring database shows that abundance of rainbow smelt populations in Malletts Bay, the Northeast Arm, and the Main Lake varies independently in some years, suggesting that the populations are not readily intermixing (Fisheries Technical Committee 2012). Historically, walleye were thought to move along the eastern shore of the lake between Grand Isle and the mainland, to reach spawning areas in the Lamoille and Missisquoi Rivers and in Missisquoi Bay; the Sandbar causeway blocked their access to the Lamoille River, and necessitate a longer, westward journey to reach Missisquoi Bay (Halnon 1963, Marsden and Langdon 2012). The effects of this barrier on walleye migrations may in part be the cause of a steady decline in walleye abundance since the mid-1900s (Marsden et al. 2010).

In large lake systems such as the Great Lakes, fish are challenging to track. The Great Lakes Acoustic Telemetry Operational System (GLATOS) project (http://data.glos.us/glatos/), which uses acoustic receivers in the Great Lakes to detect individual, acoustically tagged fish when they swim within range, is limited to arrays of receivers located within a few kilometers of shore, leaving much of the lake habitat without coverage. Lake Champlain offers the potential to study complete movements of fish at a meso-scale compared to the Great Lakes. The narrow profile of Lake Champlain permits coverage of a significant proportion of entire lake with a relatively small number of receivers, greatly enhancing our insights into fish behavior. For example, in many portions of the lake a receiver in the center of constriction points covers the width of the lake. Broadly, our goal is to establish an acoustic tagging infrastructure for Lake Champlain that can be utilized by multiple projects and investigators, similar to the GLATOS program. We propose to use funding from this grant to supplement our newly deployed, but limited array of receivers in Lake Champlain to better understand fish movement, or lack of it, among fragmented habitats throughout the northern half of the lake (Fig. 1). Currently, information on fish movement among the fragmented regions of Lake Champlain is non-existent. Deployment of a complete array system at all major constriction points will provide a first-time examination of if, when, and under what conditions fish move through man-made constriction points. We anticipate that the array will be utilized by other investigators for a diversity of projects in the future.

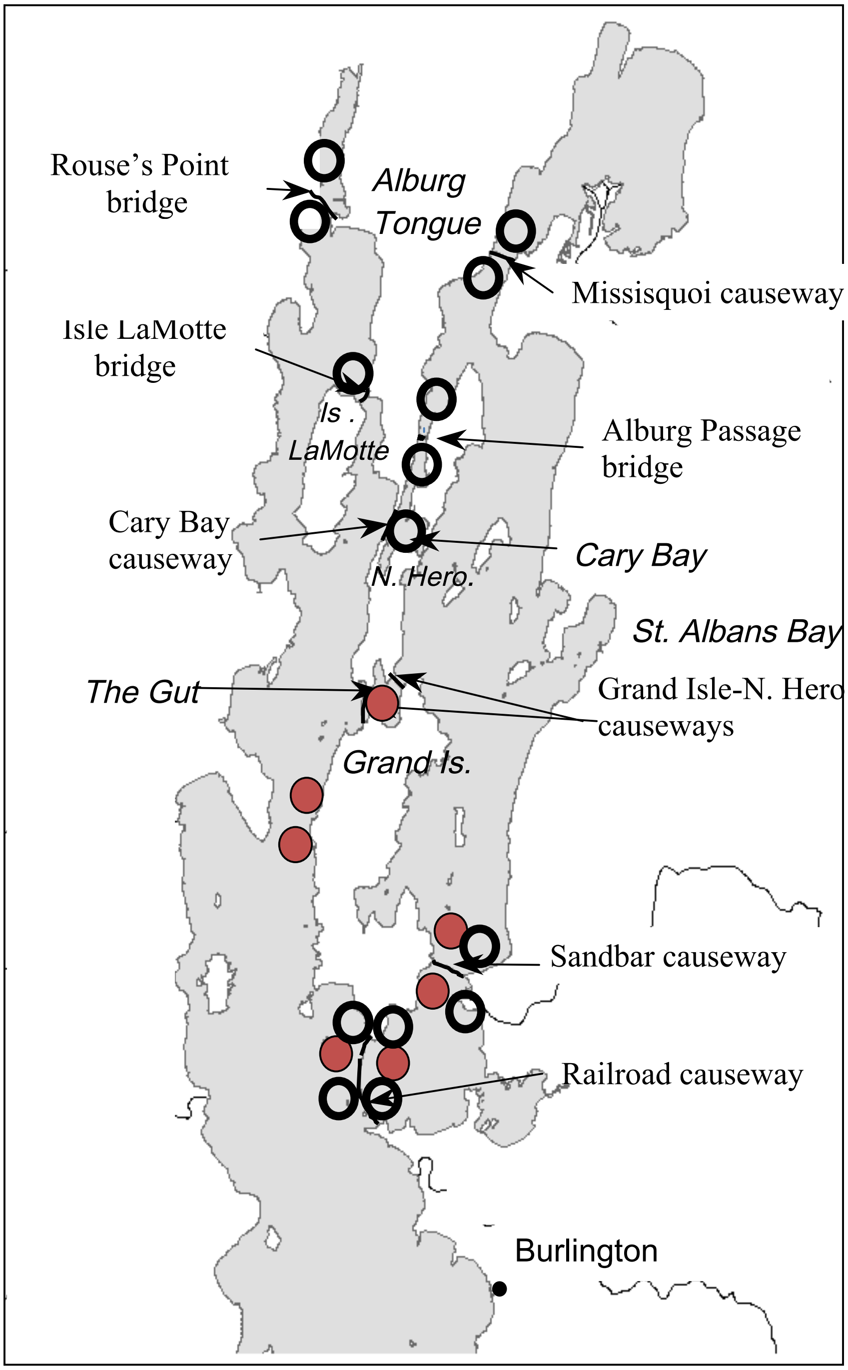

Figure 1. Lake Champlain showing major bays, causeways, and seven existing acoustic receiver locations. Filled circles indicate recievers deployed in 2013; unfilled circles are proposed receiver locations for this project. Three other receivers were deployed on lake trout spawning reefs further south in October 2013.

Statement of Benefits

The project will establish a basic acoustic telemetry network that will be available indefinitely for future research. In addition to the array of receivers, we will build a working relationship with VEMCO, the manufacturer of the telemetry system, and develop skills for fish tag implant surgery, receiver deployment and downloading, and data analysis that will be transferrable to future studies on multiple species. An initial array of 12 receivers has just been deployed (October 2013) with Great Lakes Fishery Commission (GLFC) matching funds; the current request is to augment this array to complete coverage of the constriction points between fragmented basins in the lake (Fig. 1) and to purchase additional tags to increase sample size. The acoustic array will be linked with those that already exist in the Great Lakes (GLATOS) and in the Hudson River up to the beginning of the Champlain Canal at Troy, NY, enabling us to detect fish that move between these systems (Fig. 2). Likewise, an acoustic telemetry array is being planned for the upper St. Lawrence River (Jonah Withers, Purdue University; John Casselman, Queens University, pers. comm.); linkage with that project would enable detection of fish that migrate between Lake Champlain and the St. Lawrence via the Richelieu River. Our network will be integrated into the existing data management system for archiving and sharing acoustic tag detections (GLATOS).

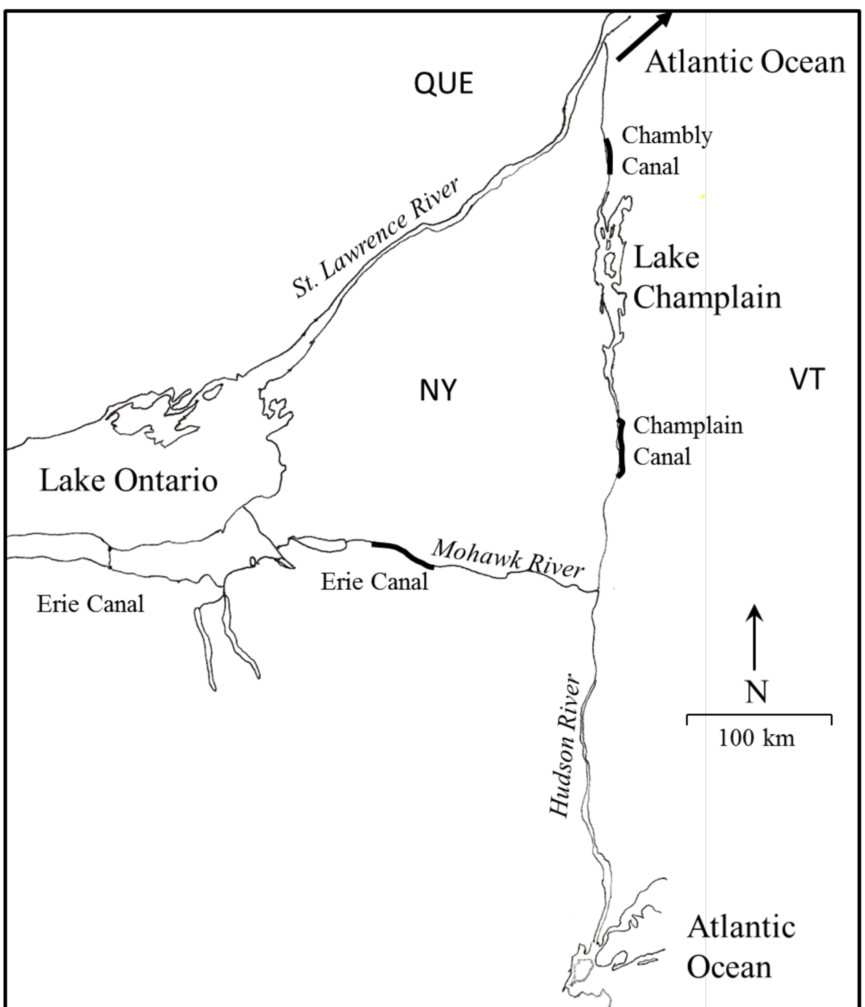

Figure 2. Geography of connections between Lake Champlain, the Atlantic Ocean, and Great Lakes via the Richellieu/St. Lawrence River system, the Hudson River, and Erie Canal.

The initial application of the acoustic telemetry array will provide a first step in evaluating the effect of extensive habitat fragmentation on fish movements in Lake Champlain. Understanding the role of causeways as barriers to species such as lake whitefish, rainbow smelt, and walleye is critical for effective management of these species, i.e., determining whether species should be managed as single, panmictic populations or isolated sub-populations in each bay. Combining fish movement data with genetics studies will provide a multidisciplinary approach to look at the interaction of behavior, metapopulation structure, and connectivity that will be much more powerful than using either approach alone.

To study the effect of habitat changes on movements of fish in Lake Champlain, we will begin by studying lake whitefish. In the 1800s, lake whitefish supported a small but thriving commercial fishery in Lake Champlain, with primary harvest occurring in the south lake, Missisquoi Bay, Alburg, Swanton, and near St. Albans Bay (Halnon 1963, Marsden and Langdon in 2012). Populations in the Main Lake appear to be thriving, but larvae and adults are scarce or absent in other areas of the lake (Herbst et al. 2011). Significantly, larvae are abundant throughout the Main Lake, even at sites a few kilometers offshore, but have not yet been found at sites recorded as traditional fall seining grounds in the isolated bays (e.g., Titcomb and Warren 1892). This scarcity may be a consequence of reduced movement of lake whitefish to these areas, degradation of spawning areas due to increased siltation and eutrophication, or both. Areas of gravel-shale substrate extending from shore to at least 2 m depth are abundant along the Main Lake shoreline, and are likely the focus of spawning by whitefish. Areas of this substrate are also present where whitefish larvae are absent; in these areas, the gravel-shale is substantially covered with silt.

Nature, Scope, Objectives, Hypotheses, and Timeline

Nature: The proposed work is field-based, using *in situ* acoustic technology to monitor fish passage through constriction points between fragmented habitats.

Scope: The research is focused on the northern half of Lake Champlain where natural and man-made causeways create high habitat fragmentation among the regions of the lake. The link with GLATOS in the Great Lakes, the Hudson River array, and the future St. Lawrence array means Lake Champlain will be part of a regional network for fish movement.

Objectives: (1) Establish an acoustic receiver array in Lake Champlain and provide infrastructure to support multiple studies of fish movements; and (2) Determine range of individual lake whitefish movements in Lake Champlain with particular emphasis on movements in relation to barriers (causeways) that fragment the lake.

Hypotheses:

H1: Lake whitefish have limited home ranges

This hypothesis will be refuted if tagged lake whitefish are detected at two or more non-adjacent receivers. If home ranges are large, then the potential exists for whitefish to move among as well as within bays. Lack of detections of any individual whitefish at more than one receiver does not conclusively indicate that home ranges are small, however, only that our sampling may be insufficient to detect these movements; however, frequent detections at a single receiver throughout the year would provide strong support of this hypothesis.

H2: Causeways obstruct seasonal movements of lake whitefish between spawning, overwintering, and summer feeding areas

This hypothesis will be refuted if individual tagged lake whitefish are detected by receivers on both sides of either Sandbar or the Island Line causeways. Movement of several individuals between bays, or a few fish observed multiple times moving between bays, would indicate that movement through the causeways is not highly restricted. As with Hypothesis 1, this hypothesis is not supported if whitefish are not observed to pass through causeways.

H3: Movement of lake whitefish between bays is limited to seasons when there is no thermal stratification.
Lake whitefish is a coldwater species; during the summer they spend the majority of their time below the thermocline in cold, hypolimnetic waters. To pass between bays a whitefish must not only find a small gap in a large barrier, but in summer they must also venture into thermally stressful habitat. If movement of whitefish is largely associated with spawning, then movement from summer feeding areas to fall spawning areas can occur after the lake has turned over (i.e., thermocline breaks down) and surface waters have cooled. In summer, however, movements between bays are less likely to occur. This hypothesis will be refuted if between-bay movement of whitefish is observed with similar frequency during the thermally-stratified and isothermal seasons.

Timeline: Our initial deployment of 12 receivers took place in October 2013. Tagging of 30 fish is currently underway at the time of writing this proposal and will be completed by November 2013. With funding from this proposal, we will deploy the requested 16 receivers and tag an additional 81 fish in April 2014. Data collection will be continuous with seasonal data downloads. Our MSc student (currently our technician) officially begins her program in January 2014. We expect a two-year project for this initial work (MSc thesis) and expect the first of two publications to be ready for submission in spring 2015.

Methods

Design and implementation of acoustic receiver array (Objective 1)

All acoustic telemetry equipment and support was purchased from VEMCO, coordinated with the GLATOS project through the GLFC. We are interested in passage of fish through narrow openings. Therefore, the initial telemetry array for this project focused on single receivers to detect fish within a certain area, or on either side of causeway openings; subsequent uses of the receivers and purchase of additional receivers in future projects may entail setting up a VEMCO Positioning System (VPS) array for triangulating exact fish positions.

Receivers purchased with this grant were deployed in Summer 2014, to supplement the receivers deployed in October 2013. Each receiver was attached to a 2 m long cable with a 70 kg concrete anchor and a sub-surface buoy; this system ensures that the receiver remains vertical in the water column to maximize accurate detection of fish tags. A second line was attached to the anchor with a surface buoy to enable retrieval for data download. A 50 m line was attached to the main anchor, with a small (3 kg) anchor on the other end. During deployment, this second anchor was deployed at a known direction from the main anchor, so that after surface buoys were removed in winter (to avoid ice damage), the receiver can be retrieved by grappling the line between the anchors.

Fifteen new receivers were deployed in mid-August, expanding the previous array to encompass the South Lake and constriction points throughout the northern third of the lake (Fig. 3).

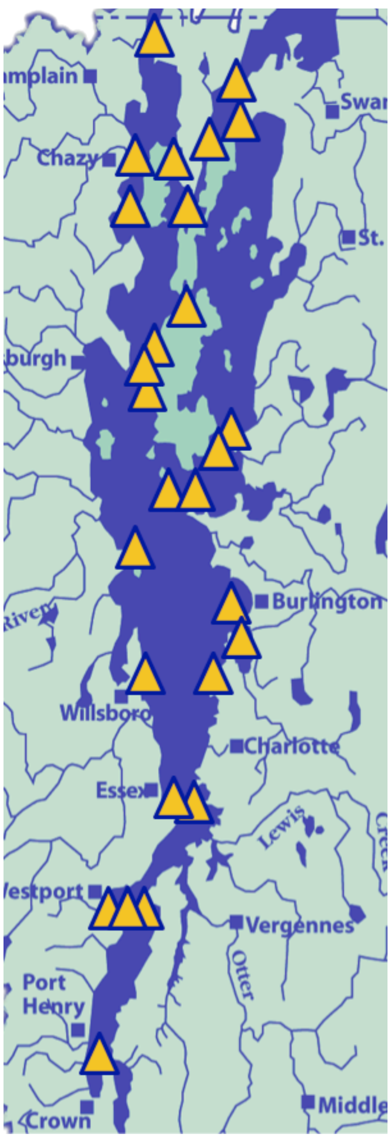

Figure 3. Map of receiver locations in Lake Champlain

Fish tagging
Fish were collected by trap net, gill net and electroshocking, to minimize stress. Fish were held in aerated tanks; prior to tag implantation, fish were anaesthetized using Aqui-S, a new drug under INAD investigation for use in fish. A small incision was made in the belly of each fish, posterior to the pectoral fins, and the tag was inserted manually so it lay just within the body cavity. The incision was closed with three stitches using resorbable suture, then the fish were placed in the aerated tank for 10-15 minutes until they resumed fully upright orientation and could be released. Each tag was set to transmit at intervals between 60 and 180 secs, with a longevity of 3 yrs.

Initial work with lake whitefish revealed that this species has a very low tolerance for anaesthesia and surgery for tag implantation. Consultation with a colleague, Dimitry Gorsky, confirmed this problem; he noted that up to 50% of whitefish he tried to tag had died within a few days of tagging. We therefore switched our focal species to walleye (*Sander vitreus*) and lake trout, as we had already tagged 30 lake trout for our study of spawning movements. Walleye migrate during spring to spawning sites in rivers; as described earlier, the Mallets Bay causeways may obstruct their passage from the Main Lake to spawning sites in Mississquoi Bay. Lake trout spawn throughout the lake, but are rarely found in the Inland Sea except in winter.

We have captured and tagged 16 walleye in Lake Champlain. The first 9 were tagged on October 10, 2014 using gillnets near Appletree Point, north of Burlington Bay. An additional seven walleye were captured via seining or electroshocking and tagged in Missisquoi Bay between April 24, 2015 and May 7th 2015. All walleye recovered rapidly from anesthesia and swam away vigorously. We tagged an additional 62 lake trout; 32 were captured by electroshocking on November 11, 2014 during USFWS assessment sampling at Whallon Bay, and 30 were captured in trap nets at Gordon Lighthouse on Nov. 4-5, 2014.

Findings
Lake field work commenced at the beginning of May, 2015, and the array of receivers has not yet been retrieved to download data on fish detections since the walleye and additional lake trout were tagged. Results from this study will be analyzed during summer, 2015, and incorporated into one MS thesis and one or more papers for publication in peer-reviewed journals.

Discussion
The addition of 15 receivers deployed in Lake Champlain has established a lake-wide acoustic telemetry array, similar to GLATOS in the Great Lakes, that will be used to facilitate a range of studies on fish movements. Initial results from the first two years of our study of lake trout spawning movements, based on detections from 10 receivers, indicate that most lake trout spend most of the spawning season at a single site (though there are several sites used), but also visit multiple sites throughout the lake. We have also done range-testing work to define how residence time at a site can be determined using single receivers.

In spring, 2015, we began discussions with the Vermont Department of Fish and Wildlife to initiate a study on lake sturgeon. Information about spawning movements and feeding areas will be valuable for monitoring and protecting this endangered species. Tagging will begin in May, and four additional receivers purchased by VTDFW will be deployed in the Winooski and Lamiolle rivers.

This project forms the basis of a MSc degree for one graduate student, funded by GLFC matching funds. Victoria Pinheiro started her graduate work in January 2014 and will defend her thesis in late 2015. Three undergraduate students, three technicians, and two graduate students have assisted with field work, fish capture, and surgeries, gaining valuable experience and skills.

No scientific presentations resulting from the work have been made since the new receivers and tags were deployed, as the data are not yet downloaded. However, several presentations have been made that discussed work to date with the CATOS array.

Science meetings and workshops:

Pinheiro, V., J. E. Marsden, J. D. Stockwell. 2014. CATOS: Pilot Studies in the Champlain Acoustic Telemetry Observation System. GLATOS workshop, Ann Arbor

Pinheiro, V., J. E. Marsden, J. D. Stockwell. 2014. CATOS: Investigating lake trout spawning behavior and the impact of habitat fragmentation. Poster presentation, Great Lakes Research Conference

Inivted public presentations:

Marsden, J. E. 2013. Lake trout restoration in Lake Champlain - and suppression in Yellowstone Lake. Central Vermont chapter of Trout Unlimited.

Marsden, J. E. 2014. ROVs, AUVs, and Acoustic Telemetry - Studying Fish with Modern Technology. Public presentation at the ECHO Center

Marsden, J. E. 2014. Lake Champlain 2014: Familiar issues, emerging issues. Lake Champlain Committee

Marsden, J. E. 2014. From CAT(o)S to fleas – updates from Lake Champlain and beyond. New York chapter, Trout Unlimited.

Marsden, J. E. 2015. Tracking lake trout with acoustic telemetry. Lake Champlain Fishing Forum

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Information Transfer Program Introduction

The Vermont Water Resources and Lake Studies Center facilitates information transfer in a variety of ways. The Center maintains a web site that highlights emerging research funded by the Center or relevant to water resources management in Vermont.

A collaborative effort of several Vermont ecological organizations was formed in 2014 to develop “ecoNEWS VT”, an online portal highlighting key results from ecological research and monitoring conducted in Vermont. The website bridges the gap between research scientists and practitioners, policy-makers, and other individuals interested in the ecology of Vermont. Numerous organizations and programs conduct ecological research across Vermont. The results of research are often not readily disseminated outside of the research community. Connecting users with relevant research can be valuable to management and policy, as well as to provide feedback to researchers about needs of the user community. Published research is distilled into articles that are accessible to people who have a basic understanding of ecological concepts. The website provides a single point of entry to the latest science elucidating our current understanding of the state and function of Vermont’s ecosystem. A quarterly email is distributed to subscribers with featured findings and links to more information. The website also contains links to the researchers and the publications. The research funded by the Vermont Water Resources and Lake Studies Center has been featured on the website and in the emails. Elissa Schuett leads this effort, producing a majority of the content for the website. Collaborators include Lake Champlain Sea Grant, the Vermont Monitoring Cooperative, the Northeastern States Research Cooperative, Rubenstein Ecosystem Science Laboratory, Rubenstein School of Environment and Natural Resources, and the Vermont Cooperative Fish and Wildlife Research Unit.

USGS Summer Intern Program

None.

Notable Awards and Achievements